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AES Monthly Forecast Techniques and Verification

by

Amir Shabbar

ATMOSPHERIC ENVIRONMENT SERVICE

DOWNSVIEW, ONTARIO

1991

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AES Monthly Forecast Techniques and Verification

by

Amir Shabbar

Climate Monitoring and Prediction

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Abstract

Monthly temperature anomaly forecasts for Canada have been made in real-time since January 1986. These forecasts make use of empirical orthogonal functions of the 50 kPa height field to filter out small-scale or spatially inconsistent circulation features. Forecast height anomalies at selected points are fitted to the five dominant empirical orthogonal functions in a least-square-error sense. The resulting reconstructed 50 kPa height anomalies are then used to specify Canadian surface temperatures by the method of multiple linear regression. Application of this technique to 108 independent forecasts from January 1986 to June/July 1990 shows significant skill over persistence in both two- and three-class forecasts for winter and spring, but falls below persistence for summer and autumn. On average, the skill of the AES forecasts is about equal to the skill of persistence and to that of the corresponding NOAA forecasts verified over Canada: 61.4% for AES compared with 60.7% for persistence and 59.9% for NOAA. Regionally, the AES forecast scores are highest for western Canada and for the East Coast in spring. Persistence scores are high over the Canadian Arctic especially in summer and autumn. The skill of the AES forecast at 50 kPa is above chance in all months except June, and above persistence in nine out of 12 months.

Résumé

Les prévisions des anomalies mensuelles de température pour le Canada ont été effectuées en temps réel depuis janvier 1986. Ces prévisions reposent sur l'utilisation de fonctions orthogonales empiriques du champ d'altitude à 50 kPa. On peut ainsi éliminer les caractéristiques de circulation se présentant à une petite échelle ou incohérentes dans l'espace. Les anomalies d'altitude des prévisions à des points sélectionnés sont ajustées aux cinq fonctions orthogonales empiriques prédominantes suivant les erreurs des moindres carrés. Les anomalies d'altitude à 50 kPa reconstituées, qui en résultent, servent alors à spécifier les températures de surface du Canada suivant la méthode de la régression linéaire multiple. En appliquant cette méthode pour les 108 prévisions indépendantes établies de janvier 1986 à juin-juillet 1990, on met en lumière un bon indice de comparaison, par rapport à l'indice de persistance, dans les prévisions tant de deux que de trois classes pour l'hiver et le printemps, mais cet indice tombe au-dessous de l'indice de persistance pour l'été et l'automne. En moyenne, l'indice de comparaison des prévisions du SEA est à peu près égal à l'indice de comparaison de la persistance, ainsi qu'à celui des prévisions correspondantes de la NOAA vérifiées pour le Canada : 61,4 p. 100 pour le SEA, contre 60,7 p. 100 pour la persistance et 59,9 p. 100 pour la NOAA. A l'échelon régional, les indices de prévision du SEA sont plus élevés pour l'ouest du Canada et pour la côte est au printemps. Les indices de persistance sont élevés pour l'Arctique du Canada, en particulier à l'été et à l'automne. L'indice de comparaison de la prévision du SEA à 50 kPa est supérieur à l'indice arbitraire pendant tous les mois à l'exception de juin et supérieur à l'indice de persistance neuf mois sur douze.

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1. Introduction

In response to the request for long-range climate forecasts by the users of climate services, the Atmospheric Environment Service started a program of preparing monthly and seasonal temperature and precipitation forecasts in 1986. Over 100 users from various sectors of the economy were selected to participate in the program and their feedback about the utility and the format of the products was solicited. In the early stages of the program, a combination using a multiple linear regression technique at the 50 kPa pressure level and the analogues were the main input in the forecast (Shabbar, 1985). Since then the procedure for making long-range forecasts has changed somewhat.

After two years of experimentation the forecast skill was evaluated. It was found that the seasonal forecasts had negligible skill, and the monthly precipitation forecasts also showed no skill compared with chance for a two-year sample. Only monthly temperature forecasts showed significant skill. Based on these results, the management committee of AES decided that the Monitoring and Prediction Division of the Canadian Climate Centre would issue monthly and mid-monthly temperature forecasts for Canada. In this report we document the current procedure used to prepare long-range forecasts. We also present an extensive verification of the 50 kPa and surface temperature forecasts. We compare our forecasts with the ones issued for Canada by the National Oceanic and Atmospheric Administration (NOAA) in the United States (Gilman, 1985). The persistence forecast, defined as the previous month's anomalies, is used as a standard for comparing forecasts throughout the study. At present a two-class temperature forecast (above and below normal) is issued. Users of long-range forecasts have repeatedly asked for a better resolution in the forecast. Here, we examine the skill of three-class temperature forecasts and demonstrate that skilful three-class forecasts can be made, by the present procedure, for some seasons and perhaps for certain situations.

2. Procedure: outline of general approach

The first objective is to obtain an upper-air pattern for the following month. This is achieved by forecasting monthly height anomalies at 50 kPa. Upper-air prediction, however, can only be made with confidence at a few geographical points when using statistical/empirical methods. The location of these points varies from one forecast to the next. Usually a few or none of these points are over the target region (Canada), so a method was developed to define the field at all points, using seasonally stratified spatial correlations. After the upper air field is defined, surface temperature anomalies can be derived from statistical specification equations.

The operational output from numerical weather prediction models (up to 10 days) from the Canadian Meteorological Centre (CMC), the National Meteorological Center of the United States (NMC) and the European Centre for Medium Range Weather Forecasts (ECMWF), and multiple linear regressions based on time-lagged correlations of the 50 kPa height anomalies enable the forecaster to make point forecasts at a small number of geographical locations at 50 kPa; see Figure 2.1.

2.1 Multiple linear regression

A set of multiple linear regression equations (Draper and Smith, 1981 give details for the derivation of these equations) provide the primary statistical guidance in long-range prediction, and although the skill varies from season to season, in general these equations explain about 10% of the variance in the historical data set (Van den Dool et al., 1984).

2.2 Dynamical guidance

The results of the numerical weather prediction models (NWP) are evaluated subjectively by the forecaster. Harnack et al. (1986) suggested that a significant gain in skill over simple persistence could be realized by the persistence of a ten-day mean formed from a suitably postprocessed forecast from numerical weather prediction models. They computed anomaly correlation scores between paired forecasts and observed maps over the Northern Hemisphere. These scores are used in assessing the correlation between medium-range NWP forecasts and the monthly 50 kPa forecast.

2.3 Persistence of 50 kPa anomalies

If an anomalous circulation feature has been persistent at the 50 kPa height field for a number of months then this information is also considered while identifying

the main forecast centres. At present, however, no objective method exists to use this information consistently.

In the selection of the main 50 kPa points, the following steps are undertaken.

Step 1. Based on the preceding month's height anomalies, multiple linear regression equations define a few centres for the coming month.

Step 2. The results of the numerical weather prediction models are evaluated subjectively and the forecaster looks for consistency between the anomaly centres forecast by the regression model and the NWP outputs.

If the regression centre is consistent with the NWP medium-range (1-10) output then it is chosen as a monthly forecast point at 50 kPa. If, however, the regression and the NWP anomalies disagree, then a subjective judgement is made by the forecaster. The judgement also involves the consideration of persistence at 50 kPa. If, for example, an anomaly that has persisted for a few months is consistent with the regression forecast then that particular anomaly is chosen as a forecast point at 50 kPa. Sometimes the sources of guidance give inconsistent forecasts and a subjective decision is required. The rationale for each forecast is documented in the technical message (FX) that accompanies each forecast.

These methods enable the forecaster to specify a few points at 50 kPa (usually between 5 to 10 points), whose locations differ from one forecast to the next. The complete domain of the forecast is a coarse latitude-longitude grid of 208 points from the North Pole to 20°N latitude.

Use is made of the empirical orthogonal functions of the 50 kPa height anomalies to extrapolate these input points to the whole forecast domain. This is achieved under the constraint that the global spatial variance equals the climatological mean variance while fitting specific centres in a least-square-error sense. This technique is described in Section 3. Simultaneous linear regression equations are then used to specify surface temperatures for 55 Canadian stations from the predicted 50 kPa monthly height anomalies (Klein et al., 1989). See Section 4 for details.

In the beginning of the long-range prediction program, the usefulness of the analogue technique was also examined (Shabbar and Knox, 1985). The analogue technique involved a great deal of subjective intervention by the forecaster. Since under optimum conditions, analogues offered skill over persistence only up to 12 to 15 days at best, the analogue technique was dropped in the preparation of the long-range forecast in 1986.

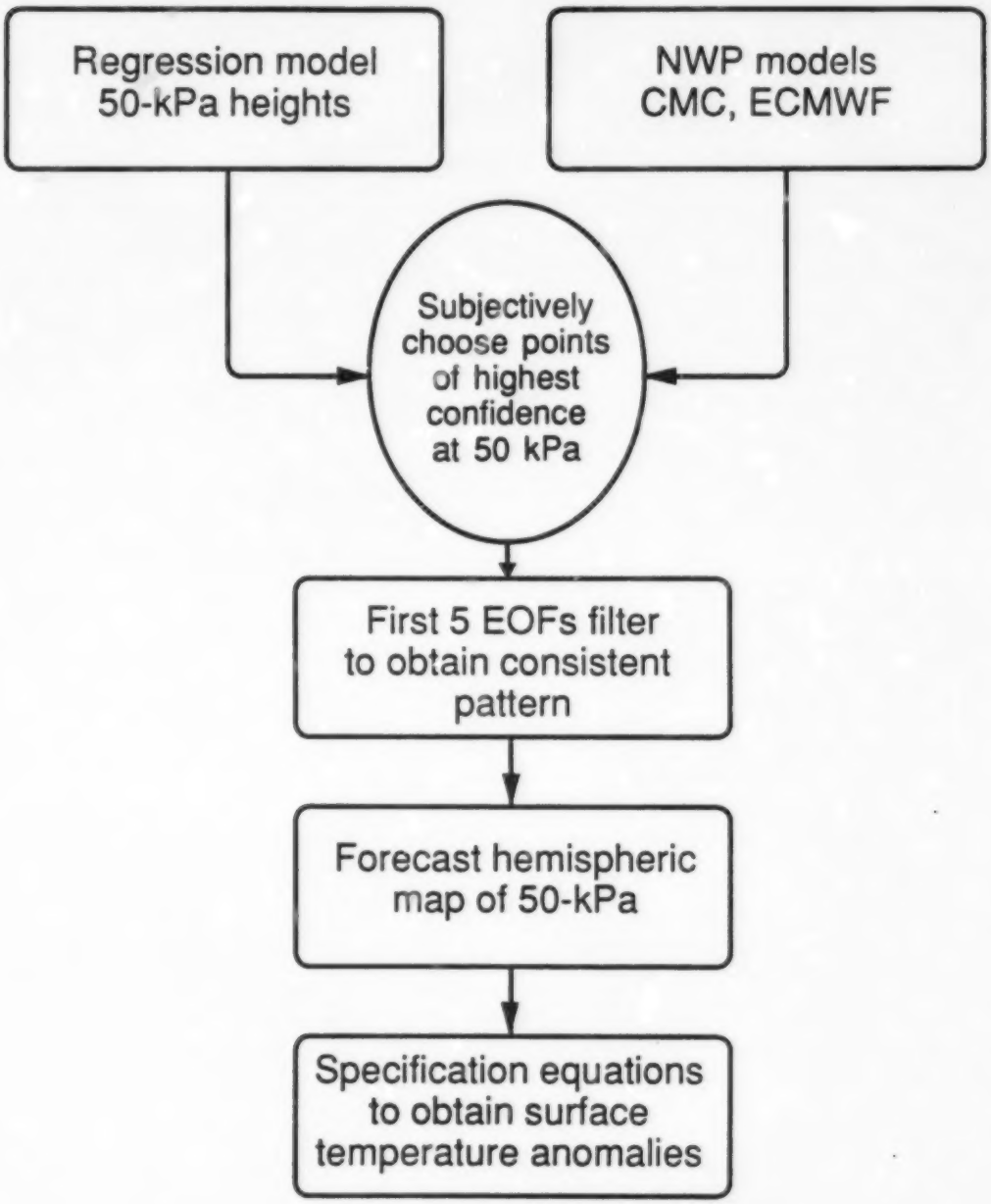


Figure 2.1. Schematic of the procedure undertaken to produce long-range forecasts in the Atmospheric Environment Service.

3. Methodology

After a few points have been specified by the forecaster for the 50 kPa height field, (e.g. by regression and ten-day guidance from NWP models), the problem is to fill the rest of the hemispheric map with the most probable pattern. Until 1987, teleconnection statistics (Namias, 1981) were used to determine the anomaly pattern over the Northern Hemisphere. There are some shortcomings in this method, e.g. spatial correlations are determined with one anchor action centre at a time and depending on the location of the centre chosen, a different anomaly pattern could emerge.

In 1987, a new and more elegant technique of extrapolating from a few specified points to the whole domain of the 50 kPa height field by means of empirical orthogonal functions was introduced (Shabbar, 1987). Empirical orthogonal functions (EOF) which are the eigenvectors of the covariance matrix of the observed 50 kPa height anomalies in the past, are used to fit the specified points in the least-square-error sense under the constraint of the global spatial variance equalling the climatological mean. The EOFs are derived from a dependent set of 5-day average observations of 50 kPa height anomalies from 1946 to 1985. Figures 3.1 and 3.2 show the first two EOFs for January and July, respectively. In terms of the explained variance per eigenvector, these EOFs describe the fields in the most efficient manner. The first five eigenvectors, which account for about 45% of the total variance on average, are used to fit the specified points. In the monthly prediction problem, since the interest lies in large-scale circulation phenomena, these first five eigenvectors, which dominate the largest area and consequently the largest time-scale, are best suited for extrapolation. This technique eliminates small-scale or spatially inconsistent 50 kPa anomalies and produces a spatially consistent pattern every time.

The fit is performed as follows:
The error of fit S_j is minimized

$$S_j = \sum_i \sum_j (y_i - A_j e_{i,j})^2 \qquad (3.1)$$

where, y_i = specified value of the height anomaly at grid point i
A_j = amplitude of the eigenvector j
$e_{i,j}$ = jth eigenvector evaluated at grid point i
i = 1, n (total number of points specified)

To find the minimum error, we solve for the condition

$$\partial S/\partial A_j = 0 \qquad (3.2)$$

for j = 1, N (total number of eigenvectors)

Now we note that the sum of the normalized amplitudes squared has a Chi square distribution. The Chi square variate is the normalized variate A'^2_j, where $A'_j = A_j/\sigma_j$ and σ_j is the standard deviation of the amplitude of the jth eigenvector. The mean of the distribution is the number of degrees of freedom N. If we restrict ourselves to the first five eigenvectors then N = 5, which gives us

$$\sum_j A'^2_j = 5 \qquad (3.3)$$

The search for a solution that satisfies both (3.2) and (3.3) involves the use of Lagrange's method of undetermined multipliers; see Woronko (1988) for details about the calculation. The optimum solution is the field that is associated with the smallest value of S.

We reconstruct the total 50 kPa anomaly field, z,

$$z_i = \sum_j A_j e_{ij} \quad , j = 5 \qquad (3.4)$$

An additional check is made on the field that is chosen. The local variance of the solution field should lie within or be closest to one standard deviation of the observed data.

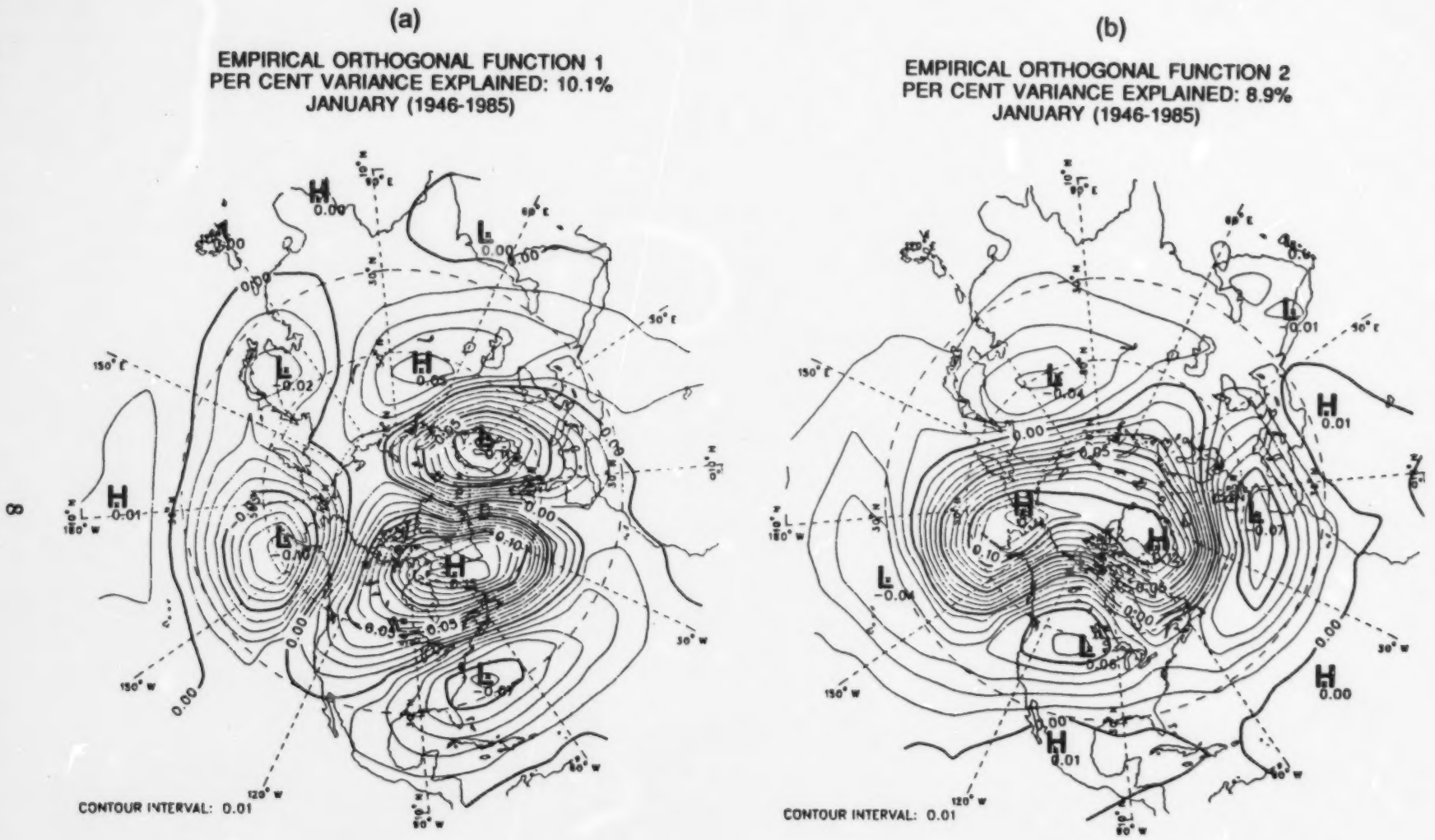


Figure 3.1 Empirical orthogonal functions of the 50 kPa height anomalies for January, (a) function number 1 and (b) function number 2.

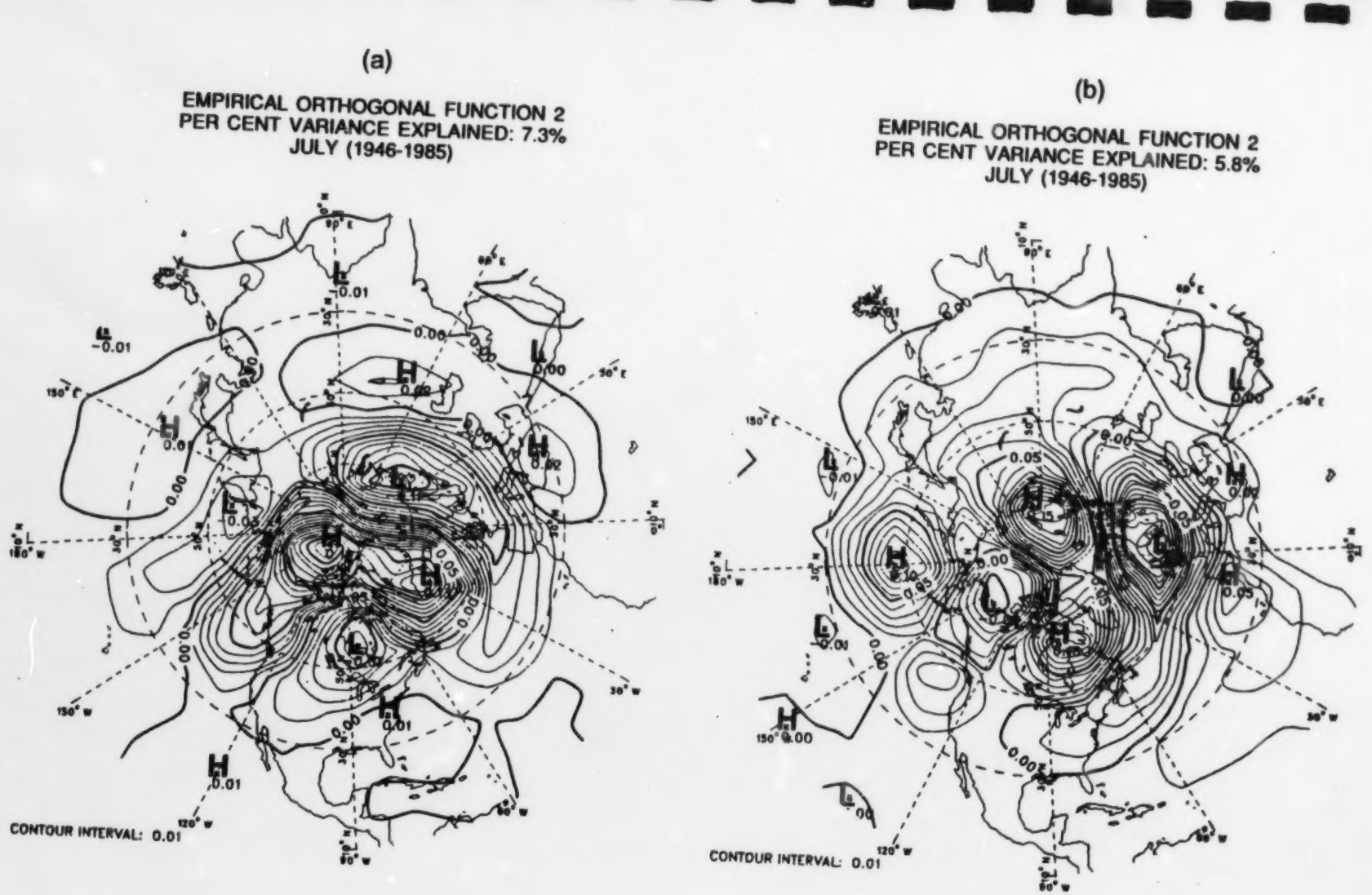


Figure 3.2. Same as Fig. 3.1 except for July.

4. Specification of surface temperatures from 50 kPa height anomalies

Once the 50 kPa height anomalies are predicted by the techniques described above, the next step is to specify surface air temperatures over Canada. Klein et al. (1989) derived monthly air temperature anomalies at 55 Canadian stations (marked by dots on Figure 4.1) by applying a forward selection screening procedure to simultaneous monthly mean 50 kPa height anomalies at 110 grid points (Figure 4.2) in the Northern Hemisphere. On an annual average, these equations explain about 72% of the temperature variance in the dependent data (1951-80). Klein et al. also conjecture that owing to the barotropic nature of the 50 kPa pressure surface, surface temperatures derived from 50 kPa are superior (about 2% more of the temperature variance is explained) than those derived from 70 kPa (Klein, 1985). Verification statistics computed (as validation) on five years of independent data (1981-85) show that the equations based on concurrent 50 kPa height anomalies perform much better than month-to-month persistence (Table 4.1). Figures 4.3 and 4.4 show the Canadian geographical distribution of mean annual correlation coefficient for independent data from 1981 to 1985 for specification equations and for persistence of the previous month's temperature anomaly, respectively.

Figure 4.1. Locations of Canadian stations where surface temperature is specified by linear regression from 50 kPa height anomalies are marked by dots. Only 35 named stations are verified (see Section 5).

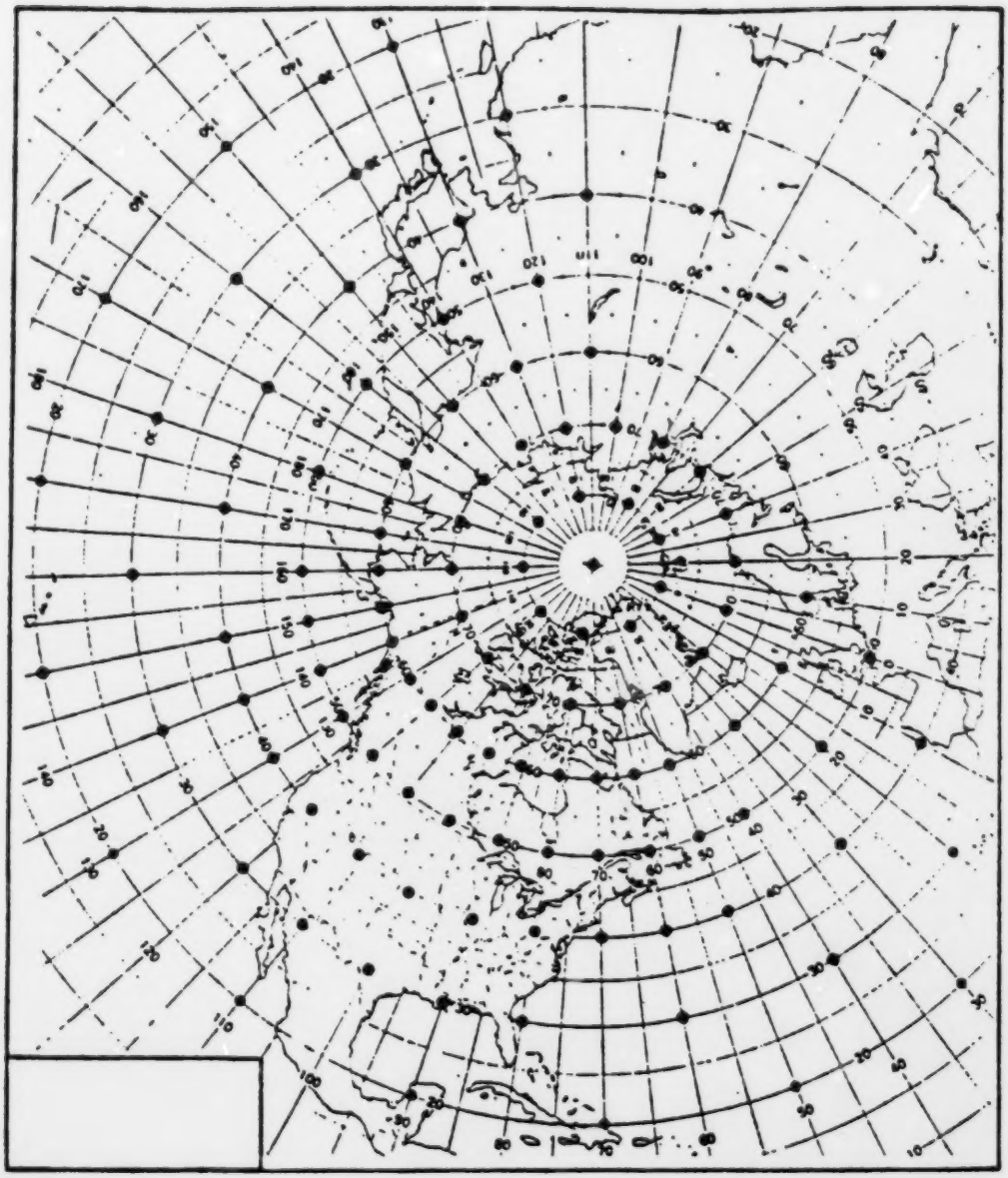


Figure 4.2. Network of 110 latitude-longitude grid points used as predictors for the specification of surface temperatures.

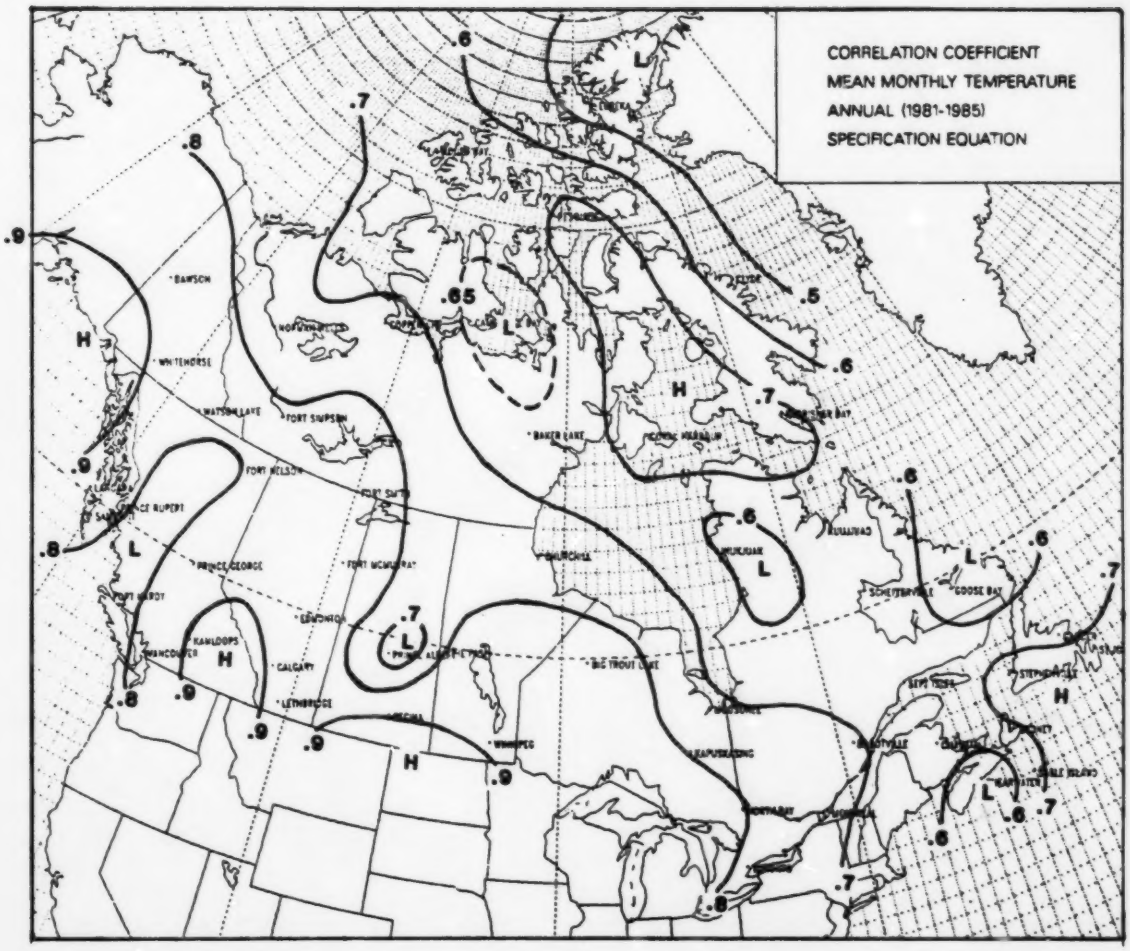


Figure 4.3. Mean annual correlation coefficient on independent data from January 1981 through December 1985 for specification from observed 50 kPa heights (after Klein et al., 1989).

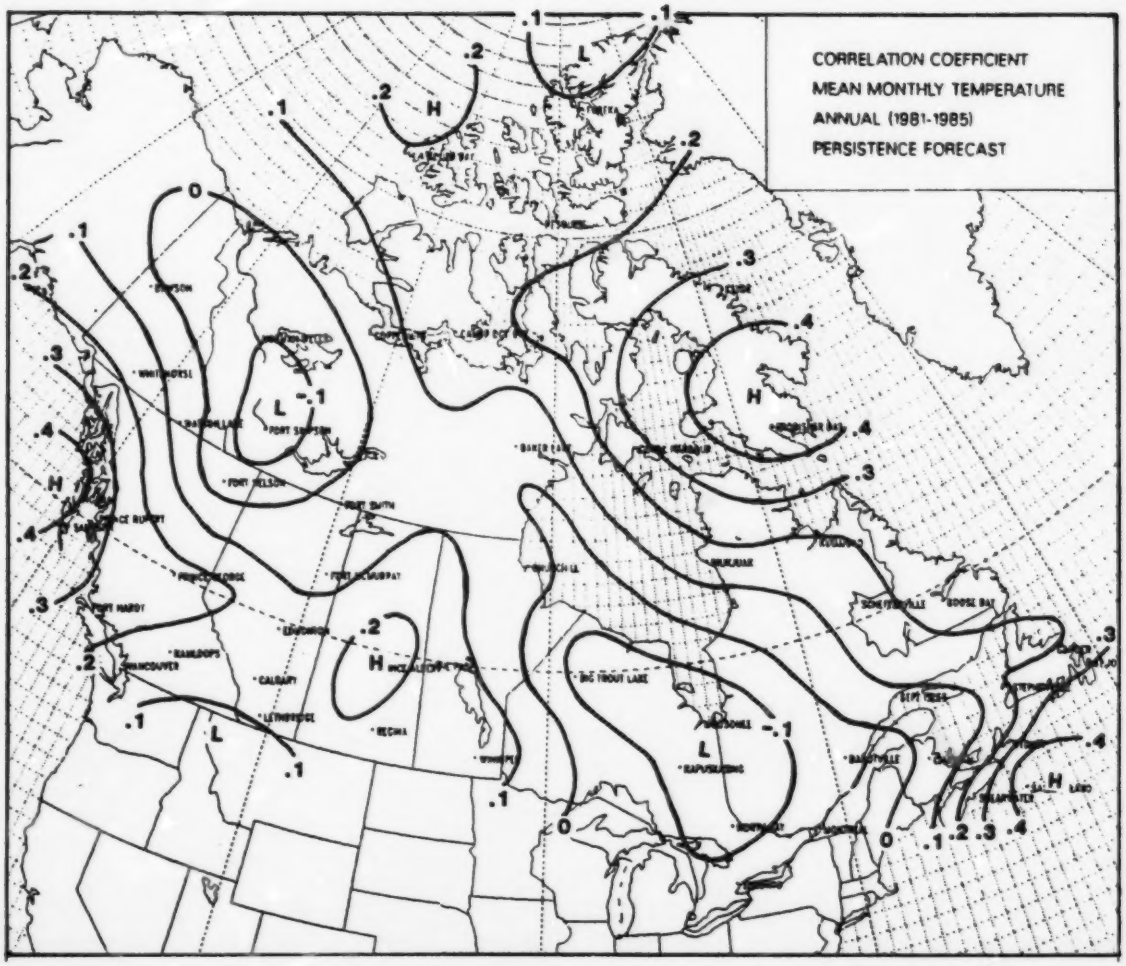


Figure 4.4. Same as Figure 4.3 except for persistence of last month's temperatures (after Klein et al., 1989).

Statistics	Specification	Persistence
Percent correct (2 classes)	80.8	60.0
Root-mean-square error (°C)	1.6	3.3
Reduction of error (%)	48.0	-78.4
Heidke skill score (3 classes)	0.44	0.13

Table 4.1 Comparative accuracy of monthly mean surface temperature anomalies in Canada specified from observed 50 kPa height anomalies. All results are averaged over independent data from January 1981 to December 1985, inclusive.

5. Verification

An extensive set of verification statistics are compiled here for monthly and mid-monthly AES forecasts from January 1986 to June/July 1990, in order to provide a quantitative measure of the accuracy of the monthly forecasts. Currently, the AES temperature forecasts are made in two classes: above and below normal. We also examine below the skill of a three-class forecast on the same sample of forecast data. To avoid any bias towards the Canadian Atlantic and West Coast regions where the density of stations is higher, a set of 35 stations across Canada are chosen to calculate the national statistics. These stations are identified on Figure 4.1. Surface temperatures from these stations are verified by the signs of the anomalies, which are defined as a departure from the 1951-80 normal. NOAA monthly and mid-monthly forecasts for the same set of 35 stations are also verified and then compared with AES forecasts.

5.1. Two-class temperature scores

(i) Time series of scores

Figures 5.1 and 5.2 show the march of monthly and mid-monthly scores for the AES and NOAA forecasts from January 1986 to June/July 1990. The per cent correct sign C is defined as

$$C = (100/n)\sum_i F_i \qquad (5.1)$$

where, $F_i = 1$ if the forecast and observed temperature anomalies have the same sign for station i

$F_i = 0$ otherwise.

Both of these forecasts have higher scores in winter and spring and lower scores in summer and autumn. The differences between the forecast and persistence is shown by the bars at the bottom of each graph. AES forecast scores were quite high in the winter of 1986-87, which was characterized by an El-Nino Southern Oscillation (ENSO) episode in the tropical Pacific Ocean. Since only one ENSO event fell in our forecast sample, at this stage it is difficult to infer any link between the forecast skill over Canada and the warming of the tropical Pacific Ocean. However, we note that in ENSO years the winter circulation over North America is marked by the Pacific/North American (PNA) pattern, which provides the forecaster with a persistent pattern to work with. The correlations between the forecast and the observed 50 kPa height

anomalies were also high in the winter of 1986-87 (Figure 5.12 (a),(b)). The AES forecasts are also high compared with NOAA forecasts. AES forecasts out-scored NOAA forecasts in 1986: 69% compared to 57%.

When the results are stratified by month (Figure 5.3), the AES forecasts are better than persistence in late winter and spring, but fall below persistence in summer and autumn. Namias (1986), investigating the skill of the 70 kPa height field in historical data over the Western Hemisphere, also showed that the forecast skill was the highest in late winter and in spring. Preisendorfer and Mobley (1984), after compiling climate forecast verification data for the United States from 1974 to 1983 concluded that the temperature was predicted best in winter and least in autumn. Analysis of our limited forecast data for Canada is reasonably consistent with these observations. Over all the months, the average of the AES forecasts is slightly better (61.4%) than persistence (60.7%). The corresponding NOAA average (59.9%) is slightly worse than persistence. In general, September and November have the lowest scores. Seasonal stratification by climatological season (Figure 5.4) confirms the above result. AES forecasts have skill over persistence in winter and spring, however, persistence outscores AES forecasts in summer and autumn.

On a yearly basis, the AES forecasts outperformed the persistence forecasts by a wide margin in 1986 but were worse than or nearly equal to persistence from 1987 to 1990 (Figure 5.5). Note that the NOAA forecast was significantly better than persistence in 1990.

In order to identify the range where most of the correctly scored forecasts occur, the forecast scores are grouped into nine classes and a histogram of these classes is plotted, Figure 5.6. Both the AES and NOAA forecasts have two peaks in the 50-59 and 71-80% ranges, whereas persistence has two peaks in the 40-59 and 60-69% ranges. Figure 5.7 shows the variability of the scores for each of the four seasons. The AES forecast has a high variability in autumn. All three forecasts have low variabilities in summer. Figure 5.8 shows scatterplots of the AES forecast scores versus NOAA and persistence scores. In general, when AES scores are high then NOAA scores are also high and vice versa. However, the points have considerable scatter. Similar observations apply to the AES forecast versus persistence scores.

(ii) Regional scores

In Figures 5.9, regional scores of per cent correct sign are plotted for each of the four climatological seasons for the 35 Canadian stations. Stations in

northeastern Canada, the West Coast and northern Ontario show high scores for the AES winter forecasts. The scores over the Canadian Prairies are relatively low (60-65%) but are still respectable. Livezey (1990) also found relatively low skill over the Midwest United States for a two-class verification in the contiguous United States. In addition, Barnett (1981), expressing potential predictability as per cent variance, showed high values for the U.S. West Coast but low values for the U.S. Midwest. Persistence forecasts are high for both the Canadian East and the West Coasts and Alberta.

In spring, both the AES and the persistence forecasts have high scores over northeastern Canada, and although AES scores are high over southern Manitoba and northwestern Ontario, even higher persistence scores are found farther west over Saskatchewan and Alberta. In summer, AES scores are generally low except for a small area of central Canada. Persistence scores are high in the Arctic (70-80%), and over the northern Prairies. In autumn, AES scores are low except over the Labrador coast and southern Baffin Island; whereas persistence scores are high in the Arctic and over the northern Prairies.

5.2. Three-class temperature scores

Using the same sample of temperature forecast data, the skill in forecasting the magnitude of the temperature anomalies was investigated by calculating three-class skill scores. The temperature distribution is partitioned in the proportion of 30:40:30 for (below normal):(normal):(above normal) classes. A 0.53 standard deviation is the border-line between these classes. Figure 5.10 shows the scatterplots of the AES forecast temperatures versus observed temperatures and persistence forecast temperatures versus observed temperatures for each of the four seasons. The regression line fitting the AES winter and spring forecasts shows a significant trend, however, the slope of the regression line is not significantly different from zero in summer and autumn. The persistence forecast shows a significant regression line in summer only (not shown). The Heidke skill score, SS is calculated as:

$$SS = (C - E)/(T - E) \qquad (5.2)$$

where T, E and C are the total, chance-expected correct and actual correct number of forecasts, respectively.

SS values are calculated for the AES and the persistence forecasts in Figure 5.11 for each of the four seasons. As for the two-class verification, the forecast skill is higher than that of persistence in winter and spring, but lower in summer and autumn. In fact, the summer forecast shows no skill relative to chance. Table 5.1 shows the normalized population distribution for each of the three classes, as defined above for the AES and persistence forecasts.

5.3 Pattern correlation for the 50 kPa height field

Since our primary forecast is for 50 kPa height anomalies, we wanted to investigate our skill for the network of 110 latitude-longitude grid points shown in Figure 4.2. Operationally, Canadian surface temperature anomalies are specified from these 110 points. Although we recognize that any given forecast would not use all the points, we still verified on the complete network. In Figure 5.12, we plot the pattern correlation r,

$$r = \frac{\sum(z_f - \overline{z}_f)(z_o - \overline{z}_o)}{\{\sum(z_f - \overline{z}_f)^2 \sum(z_o - \overline{z}_o)^2\}^{1/2}} \qquad (5.3)$$

where z_f and z_o are the forecast and observed height anomalies, respectively. The overbar represents the average over all the stations for a given forecast.

The pattern correlation r is plotted between the following pairs: (forecast, observed), (persistence, observed). Skilful forecasts at 50 kPa are generally reflected as skilful forecasts in surface temperature; for example, the November 1986 and April 1987 forecasts (Figures 5.12(a), (b)). The pattern correlation stratified by month are shown in Figure 5.13. We note that, in general, the skill of the winter forecasts is higher than the skill of the summer forecasts. The skill was above chance in all months except June, and above persistence in nine out of the 12 months.

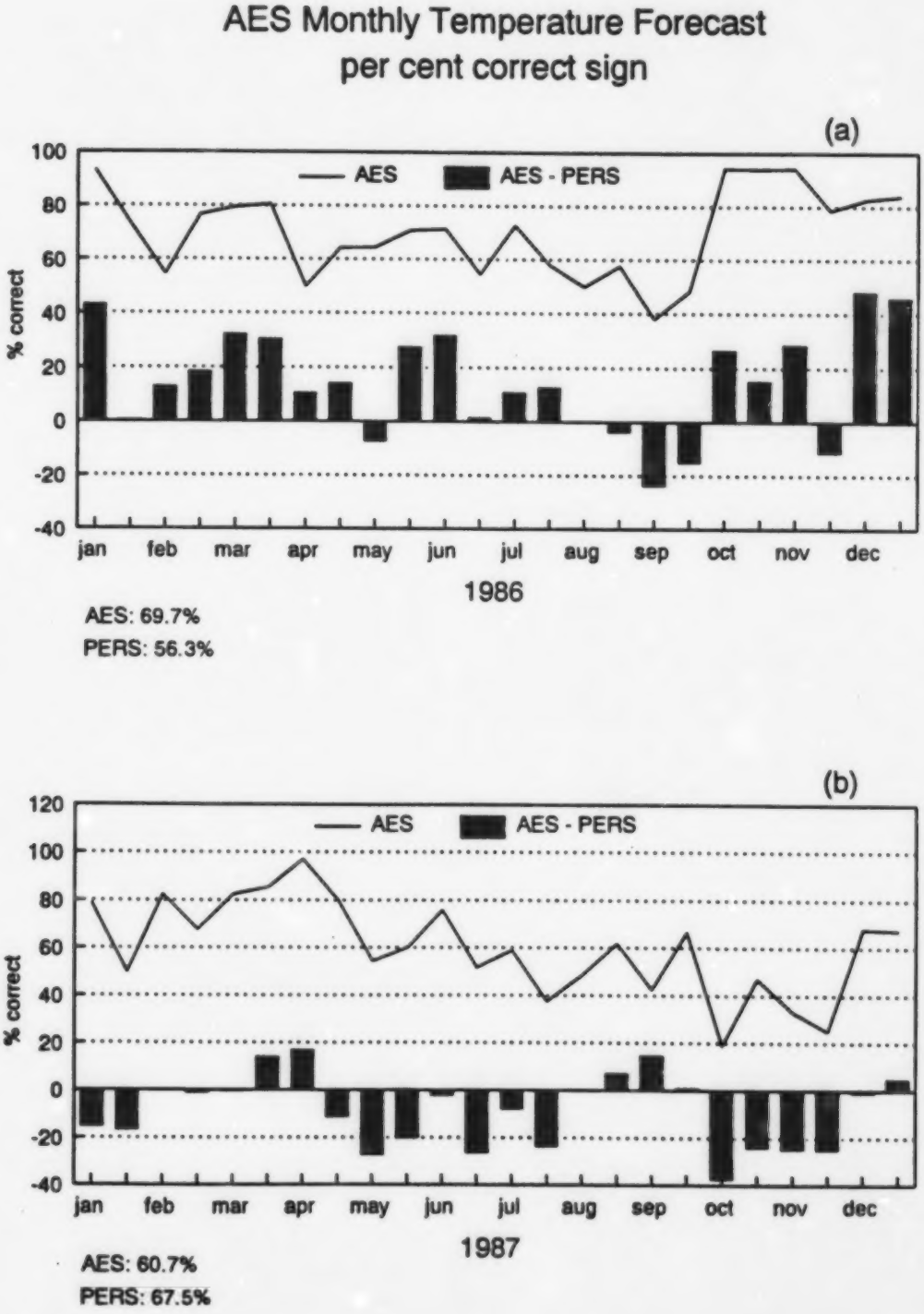
5.4. Variations in the frequencies of the 50 kPa forecast height anomaly centres

The number and locations of the forecast anomaly centres of the same algebraic sign vary from one forecast to the next. Generally, there are from 5 to 10 centres in any given forecast. Where on the hemispheric map are the centres most frequently chosen? To answer this question, the variations in frequency (as percentage occurrences) of forecast negative and positive height anomalies at 50 kPa are depicted in Figure 5.14.

From maps of the frequencies of the positive and negative centres for the winter historical data from 1947 to 1963 (O'Connor, 1969), the locations of the centres seem to coincide with the observed locations, i.e. most of the negative centres are specified over the north Pacific, associated with the Aleutian vortex. The negative centres are specified over Baffin Island, again a region of high variability in the observed data. Negative anomaly centres are also specified along an axis stretching northeastward from the Gulf of Mexico.

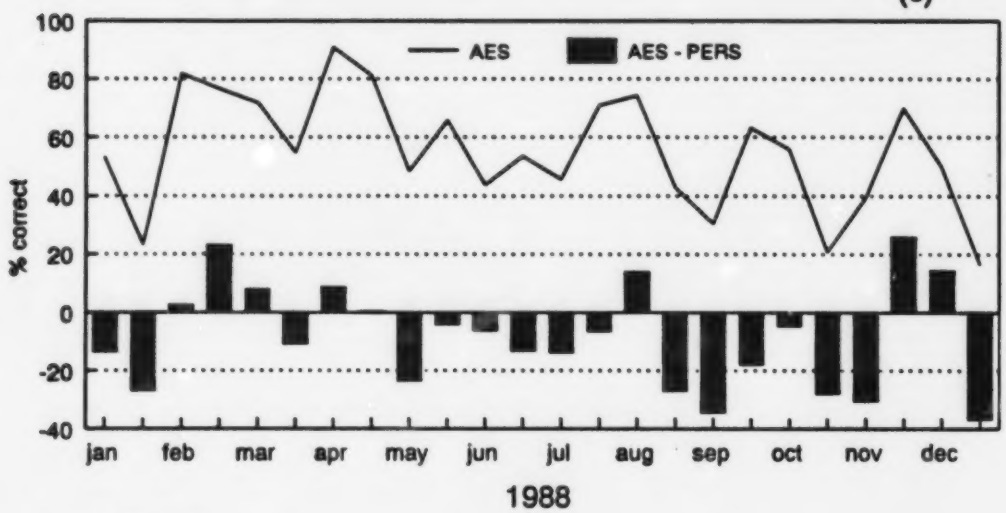
As to the positive centres, the highest frequencies of the specified points occur over the Aleutian Islands and the extreme eastern Pacific Ocean, to the west of Hudson Bay and the British Isles, and near the Gulf of Mexico and Korea. These centres are again coincident with the winter centres found by O'Connor (1968).

Figure 5.1. Per cent correct sign of the AES monthly and mid-monthly temperature forecasts for (a) 1986, (b) 1987, (c) 1988, (d) 1989 and (e) 1990. Difference between the AES and persistence forecast is represented by bars at the bottom of each graph.



AES Monthly Temperature Forecast
per cent correct sign

(c)

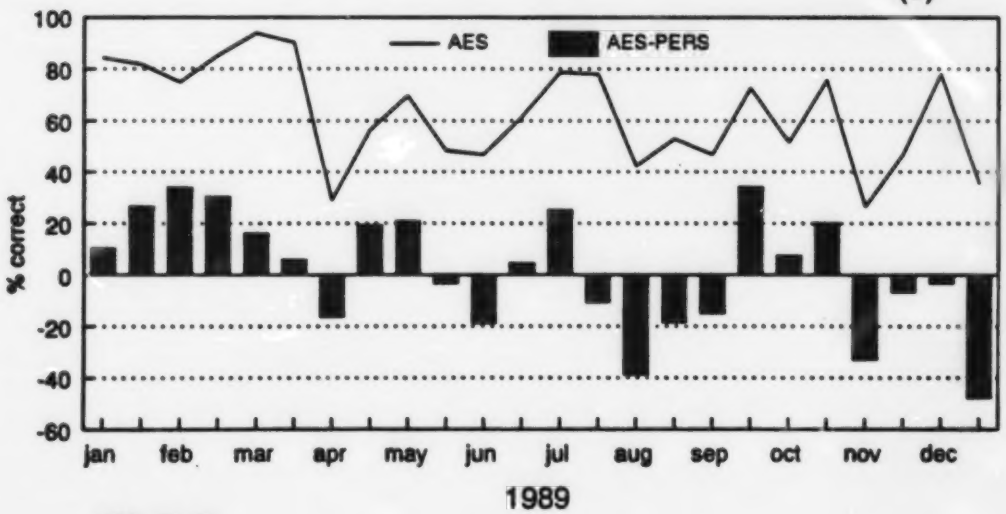


1988

AES: 57.3%

PERS: 63.8%

(d)



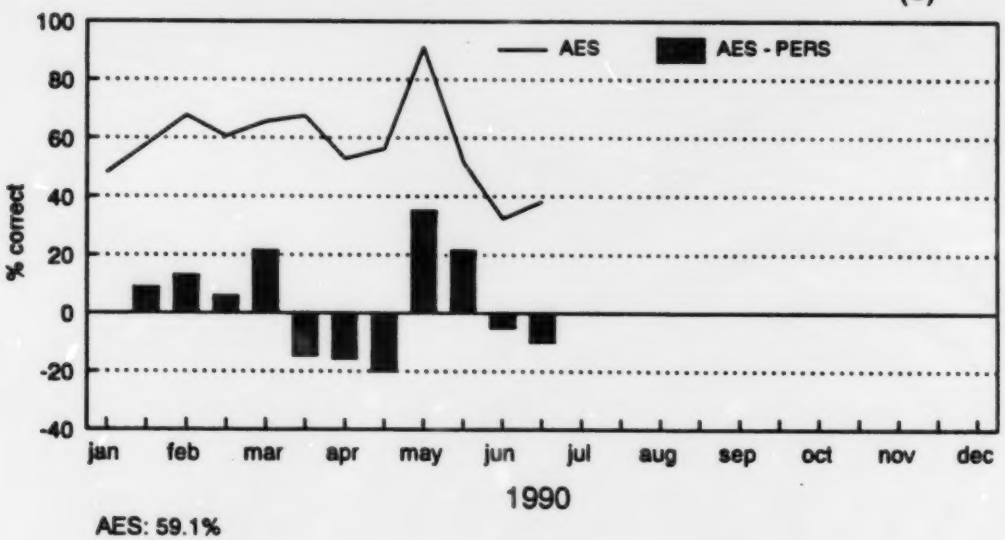
1989

AES: 60.3%

PERS: 59.7%

AES Monthly Temperature Forecast
per cent correct sign

(e)

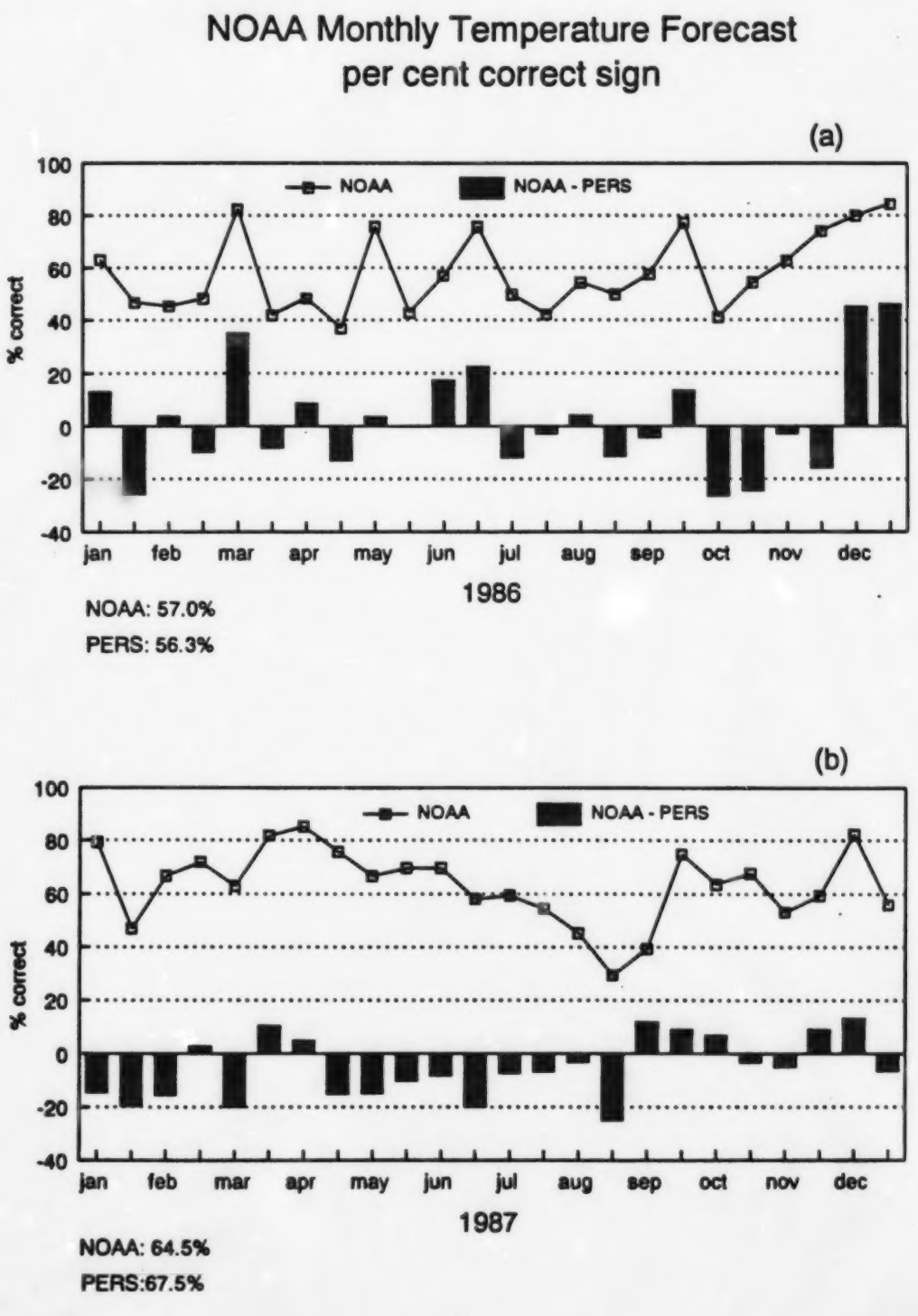


1990

AES: 59.1%

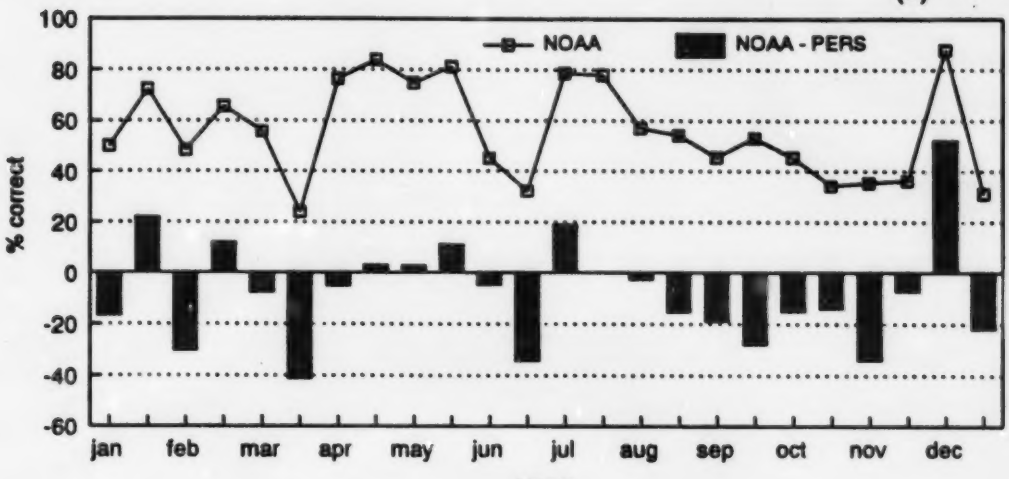
PERS: 56.2%

Figure 5.2. Per cent correct sign of the NOAA monthly and mid-monthly temperature forecasts for (a) 1986, (b) 1987, (c) 1988, (d) 1989 and (e) 1990. Differences between the NOAA and persistence forecast is represented by bars in the bottom of each graph.



NOAA Monthly Temperature Forecast
per cent correct sign

(c)

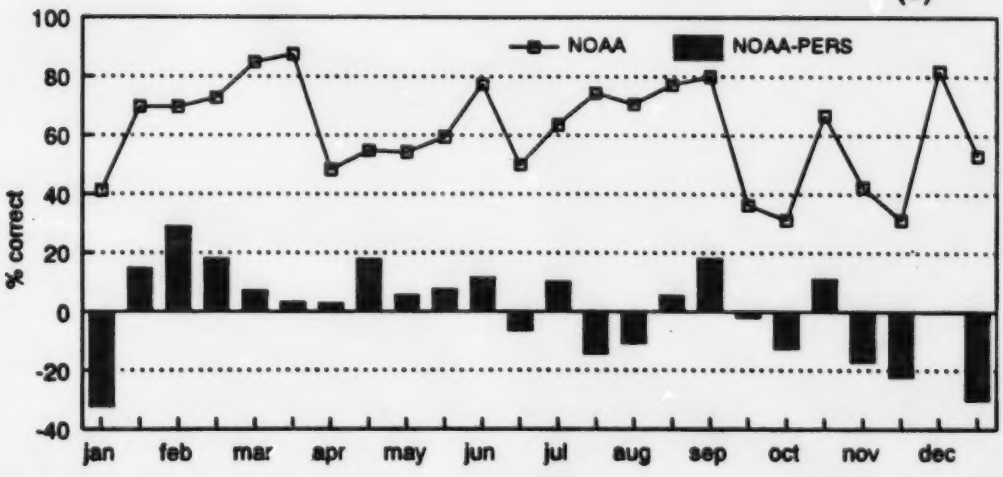


1988

NOAA: 57.2%

PERS: 63.8%

(d)



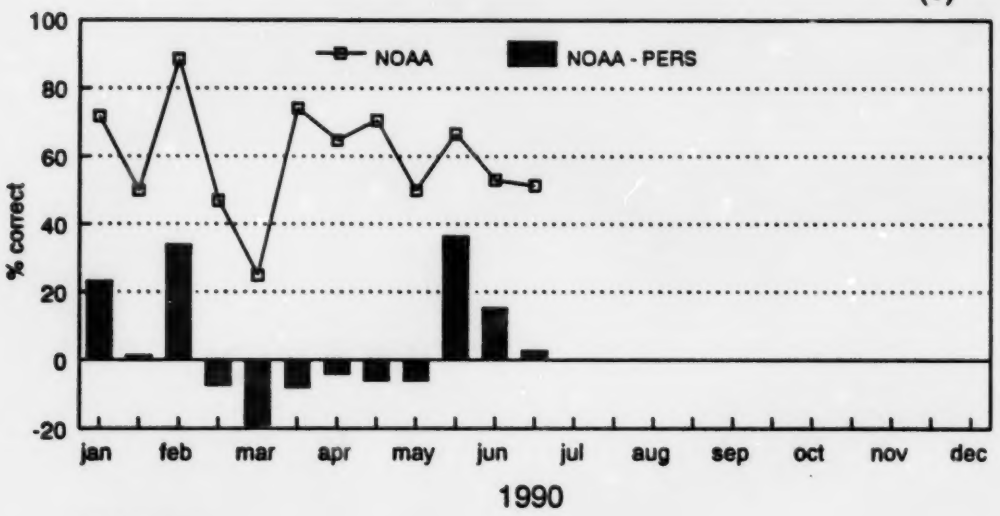
1989

NOAA: 59.5%

PERS: 59.7%

NOAA Monthly Temperature Forecast
per cent correct sign

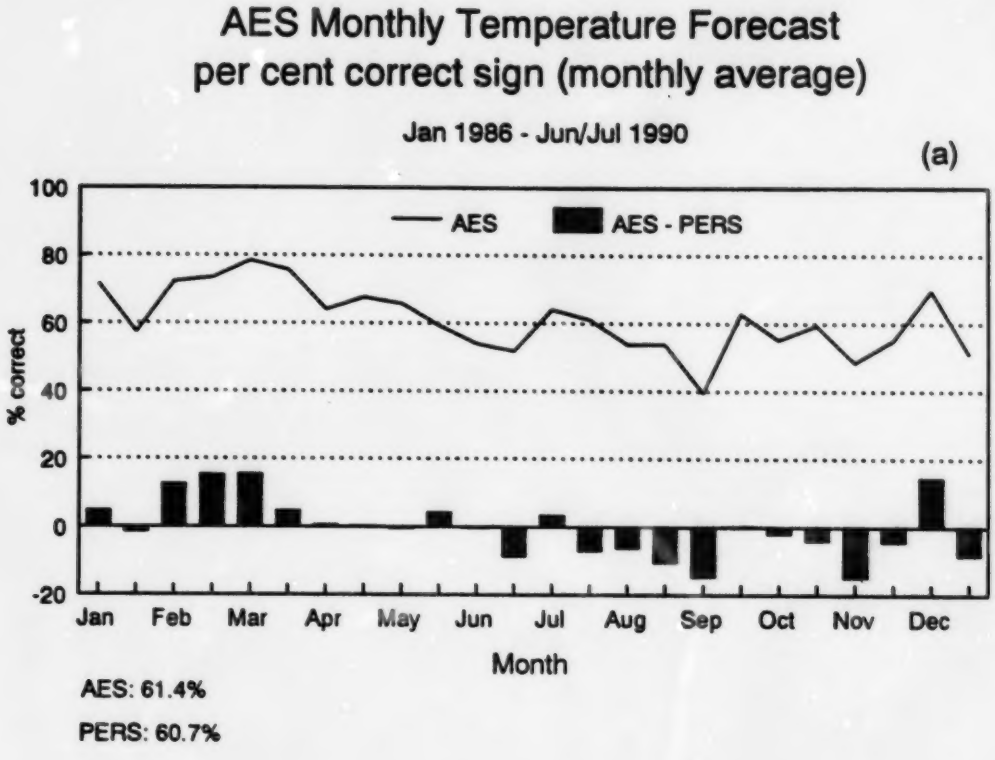
(e)



NOAA: 61.2%

PERS: 56.2%

Figure 5.3. Mean monthly scores of per cent correct sign of surface temperatures for (a) the AES and (b) NOAA forecasts. Differences from persistence are represented by bars at the bottom of the graph.



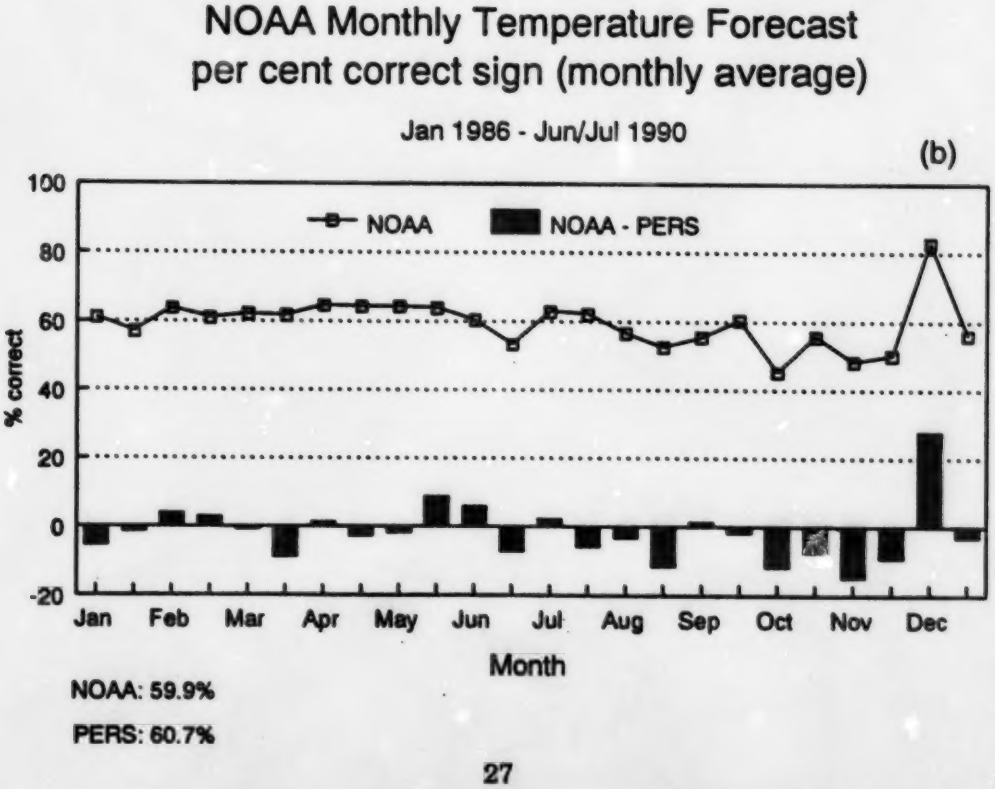
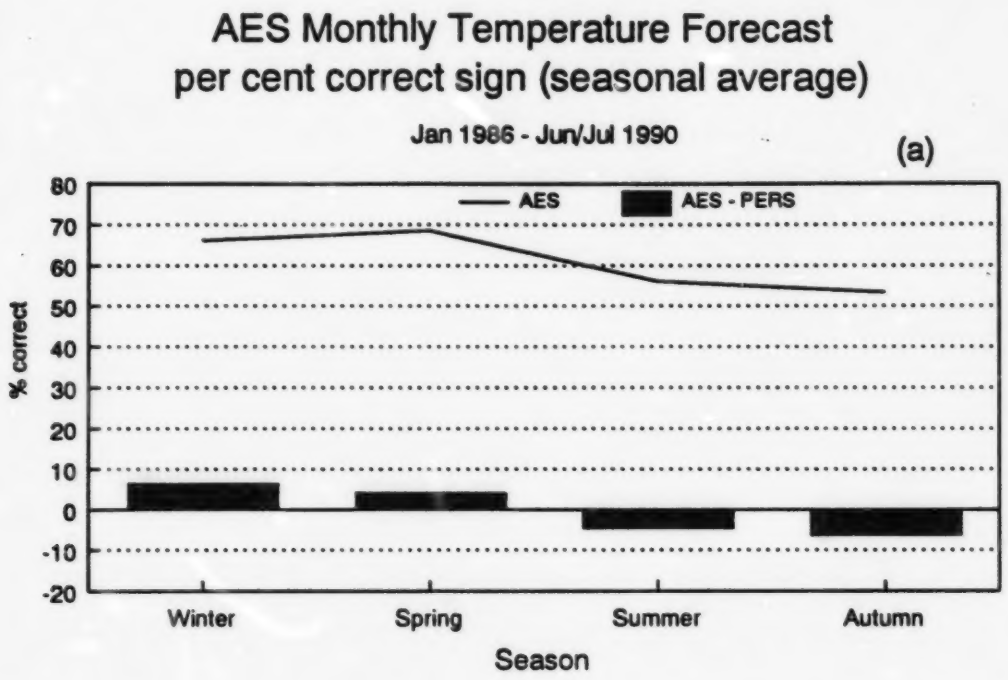


Figure 5.4. Mean seasonal scores of per cent correct sign of surface temperatures for (a) AES and (b) NOAA forecasts. Differences from persistence are represented by bars at the bottom of the graph.



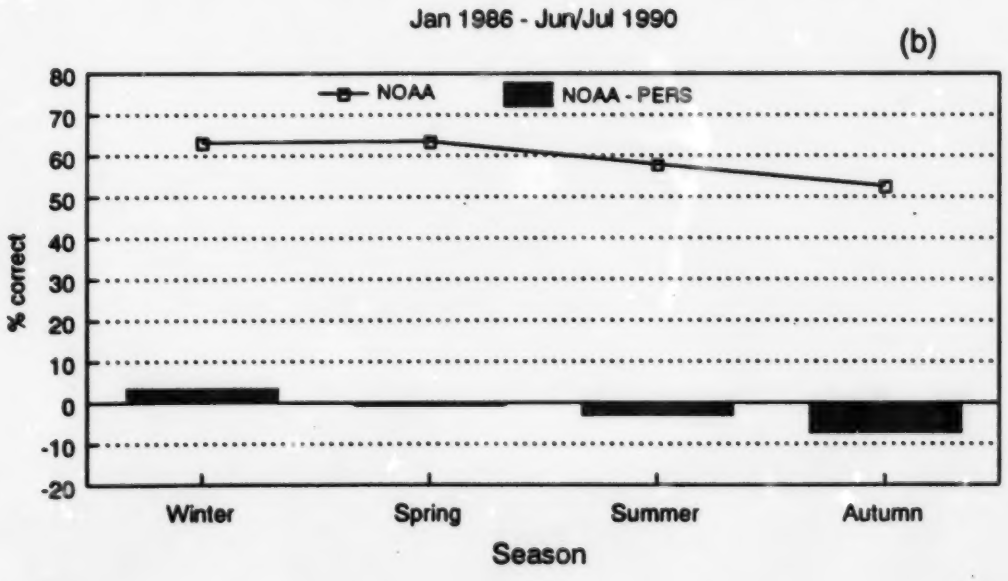
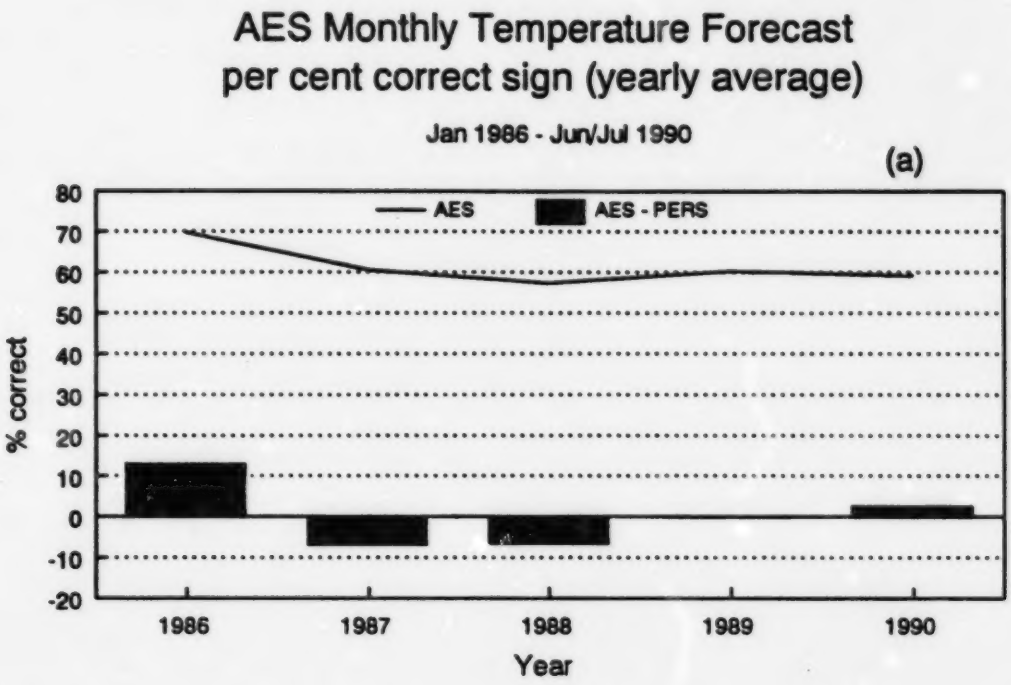


Figure 5.5. Yearly scores of per cent correct sign of surface temperatures for (a) AES and (b) NOAA forecasts. Differences from persistence are represented by bars at the bottom of the graph.



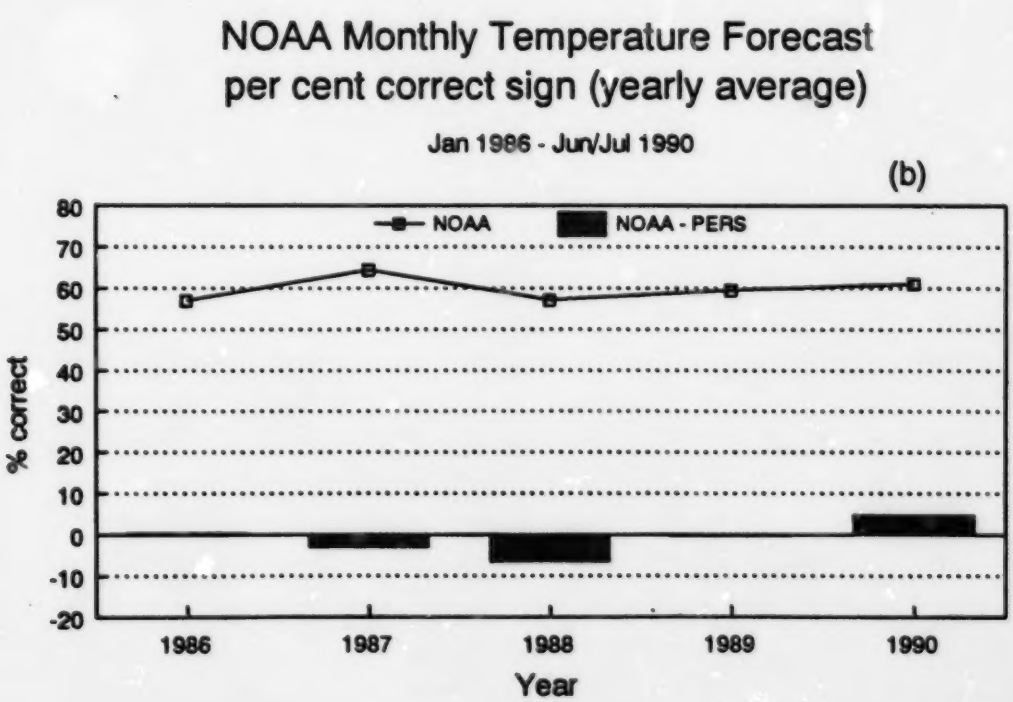
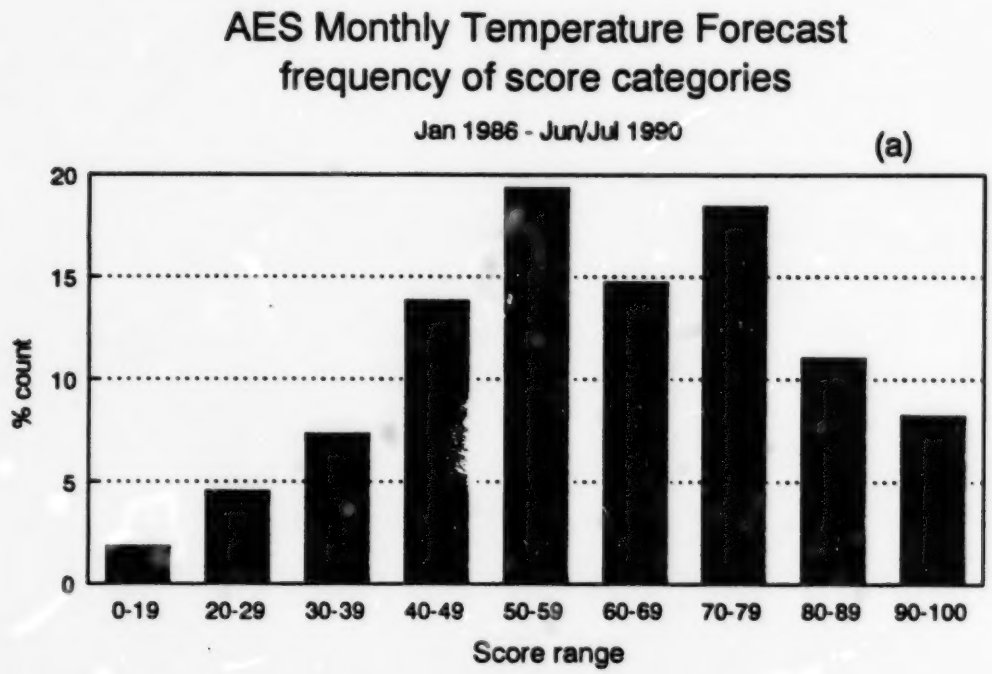
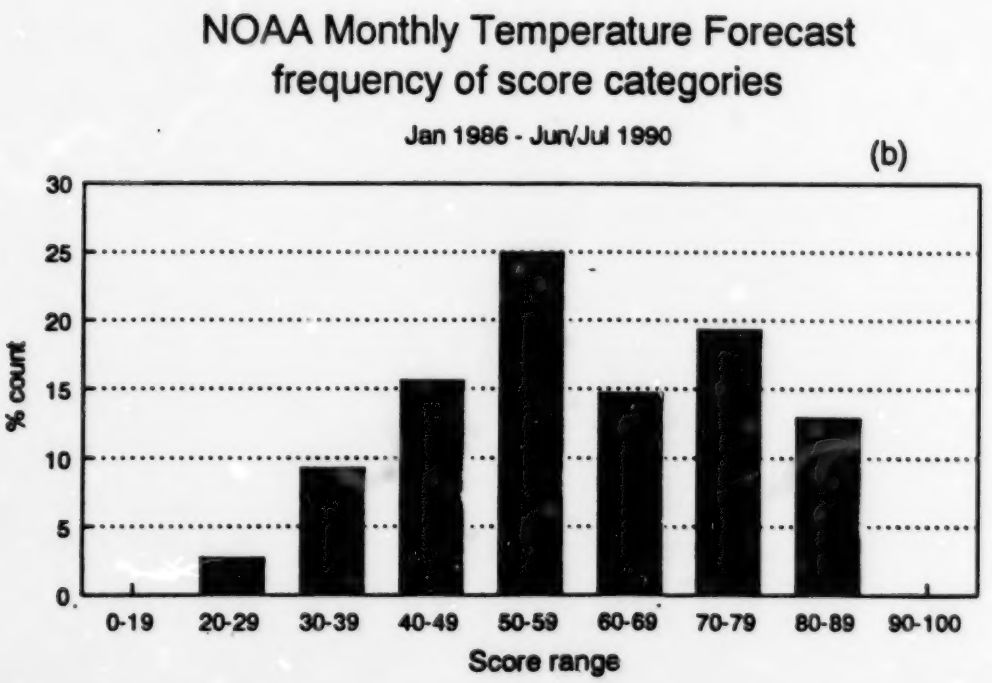
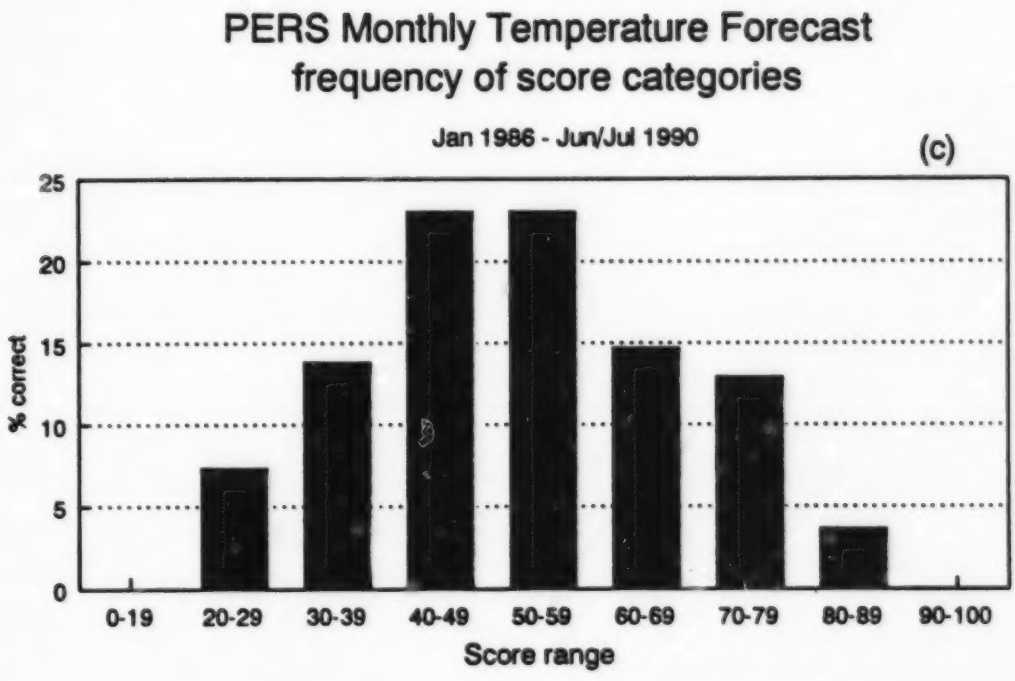


Figure 5.6. Frequencies of per cent correct sign for (a) AES, (b) NOAA and (c) persistence forecasts.






PERS Monthly Temperature Forecast
frequency of score categories
Jan 1986 - Jun/Jul 1990
(c)
% correct
25
20
15
10
5
0
0-19
20-29
30-39
40-49
50-59
60-69
70-79
80-89
90-100
Score range

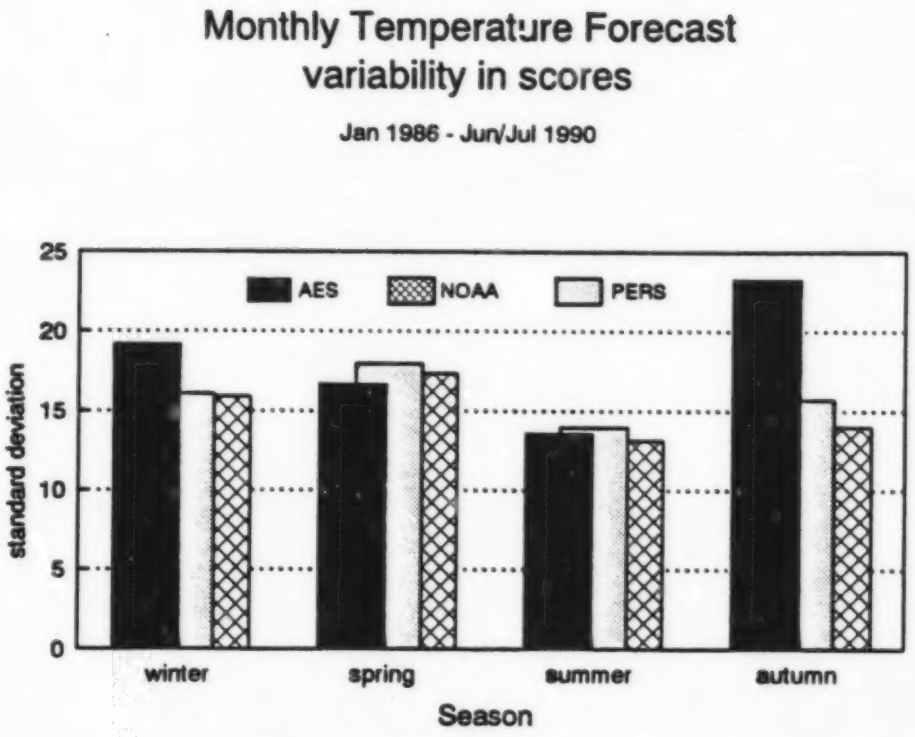


Figure 5.7. Standard deviation for the per cent correct sign scores of the AES, NOAA and persistence forecasts.

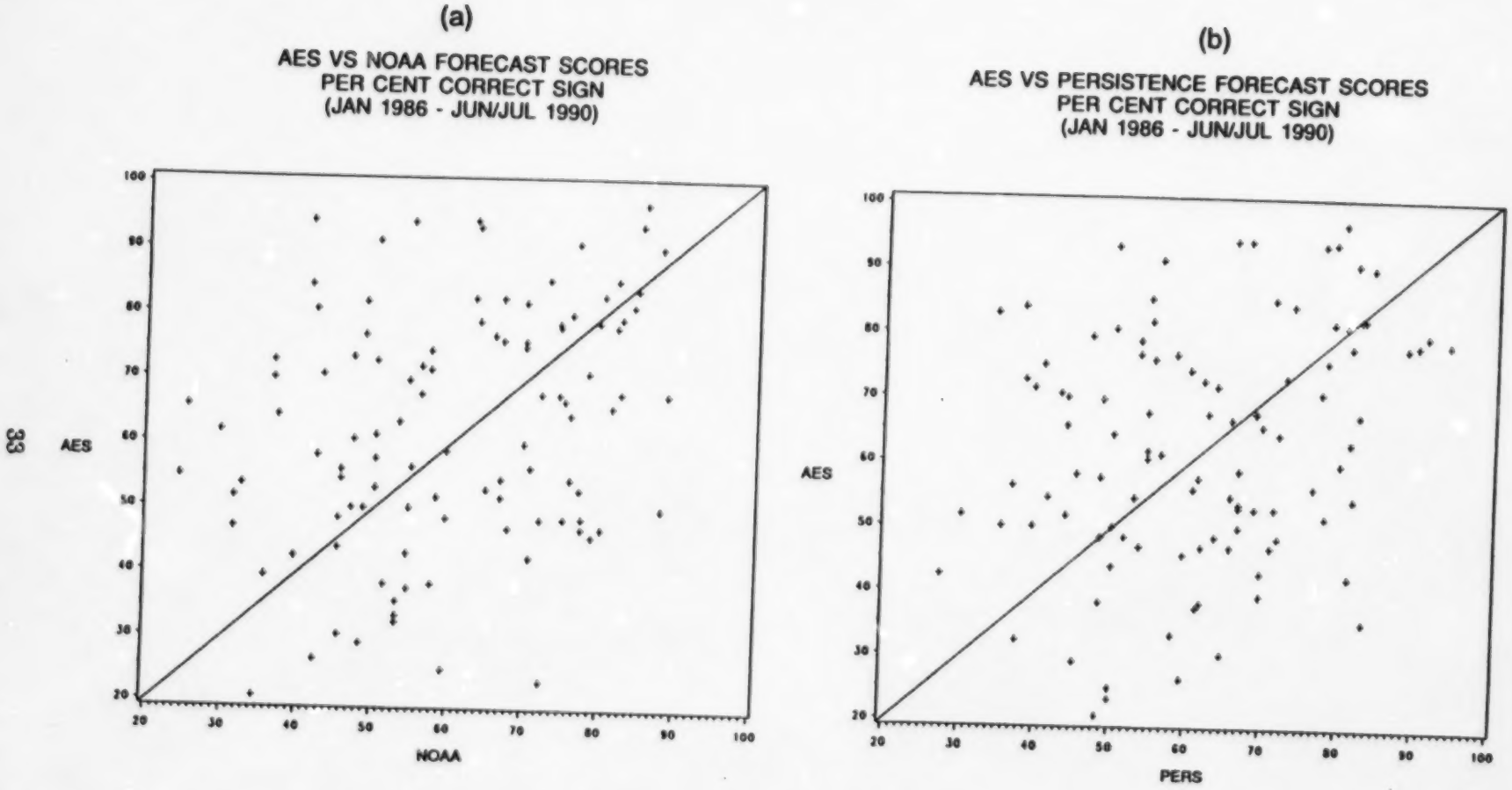
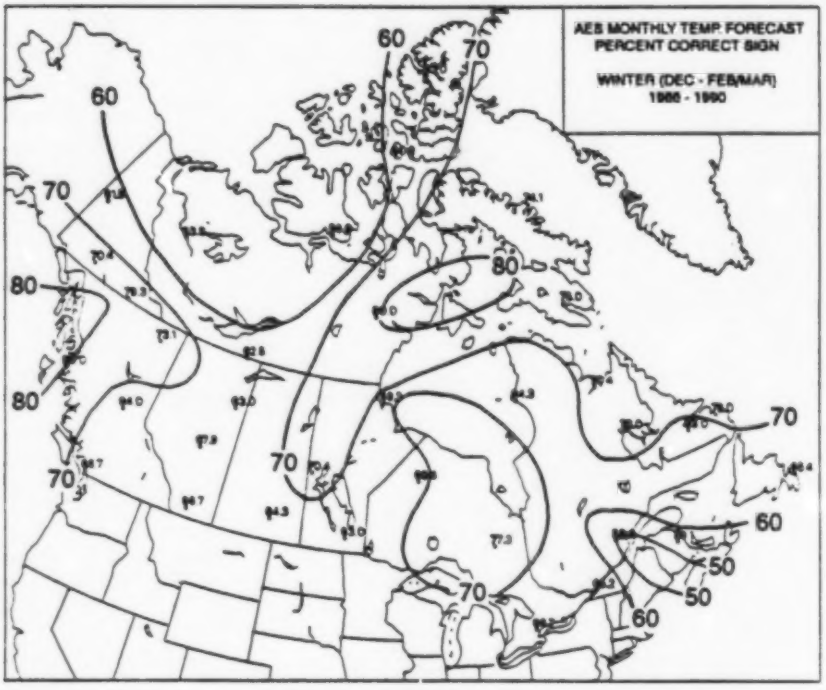
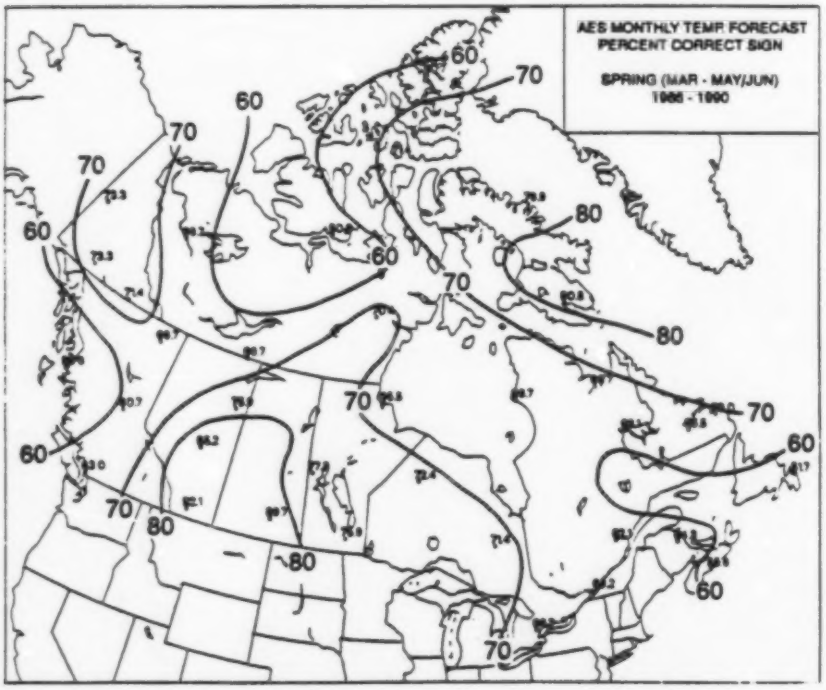


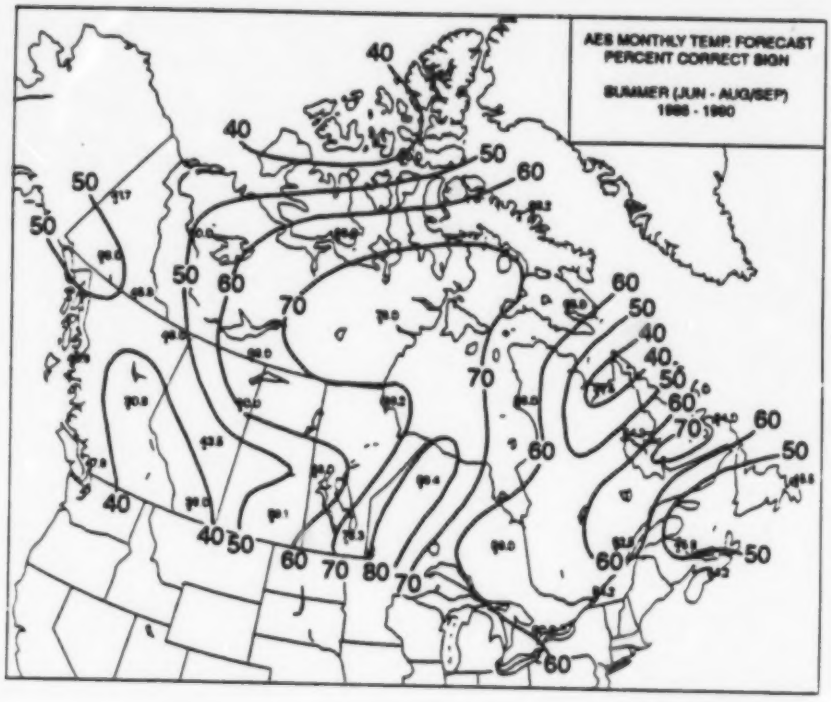
Figure 5.8. Scatterplots of the per cent correct sign scores-for (a) AES versus NOAA and (b) AES versus persistence forecasts.

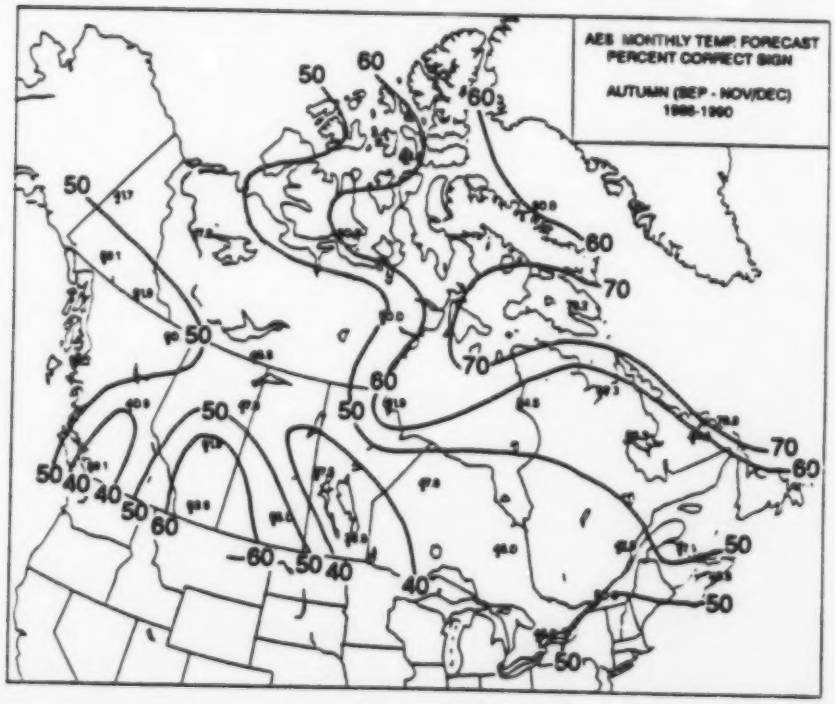
Figure 5.9. Regional per cent correct sign scores from 1986 to 1990 for (a) AES and (b) persistence forecasts for each of the four climatological seasons. Seasons are defined as follows, winter: Dec-Feb/Mar, spring: Mar-May/Jun, summer: Jun-Aug/Sep and autumn: Sept-Nov/Dec.

(a)

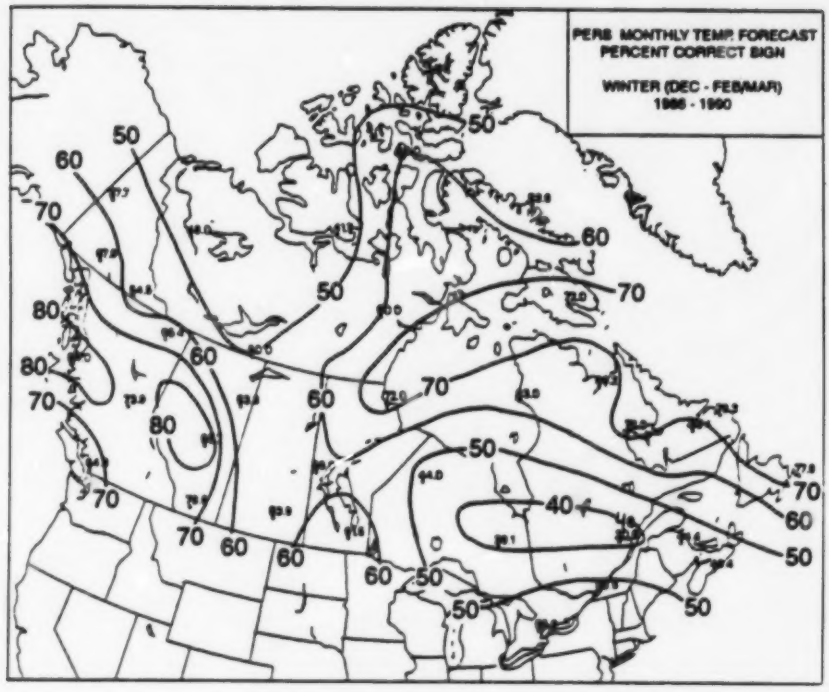


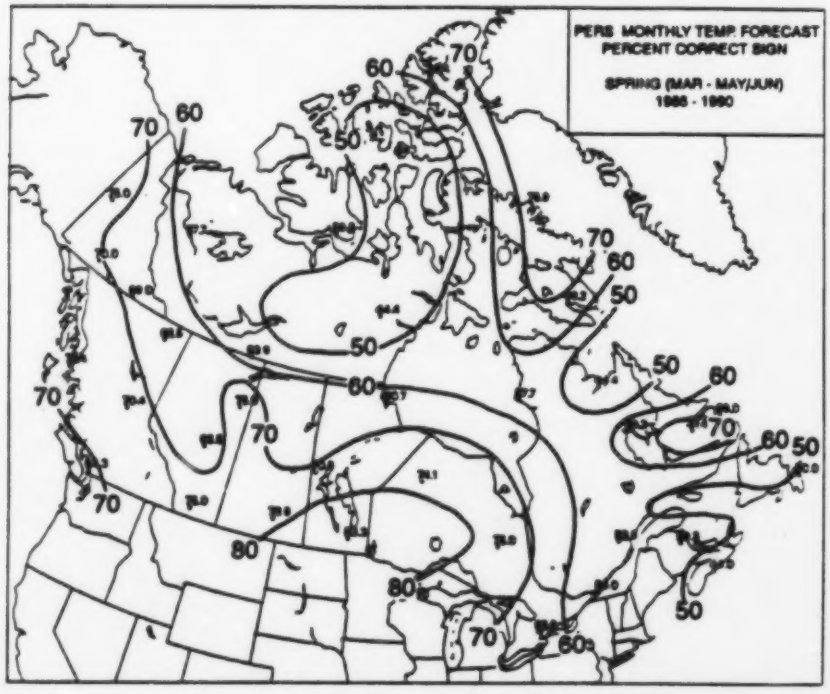


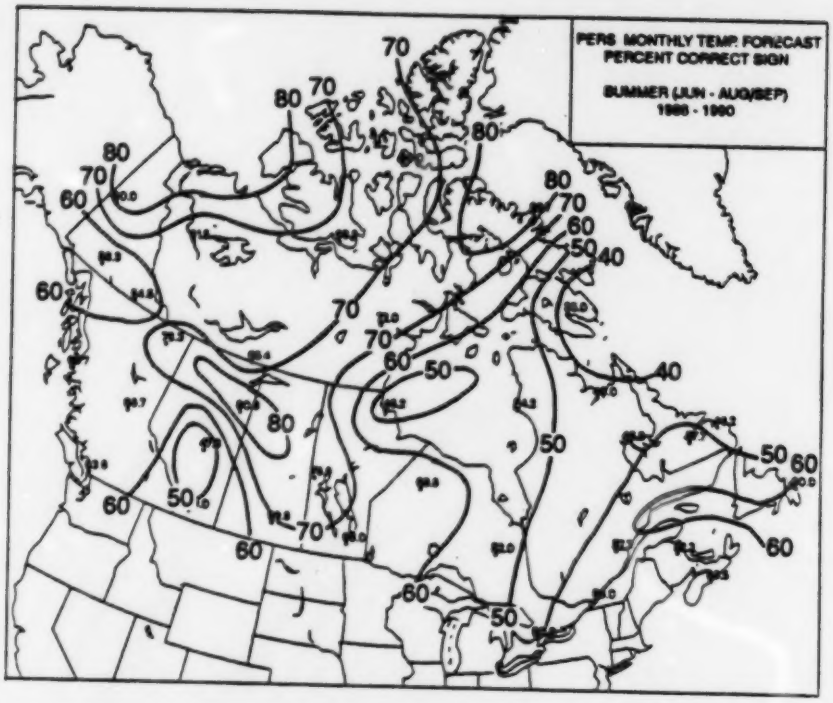

AES MONTHLY TEMP. FORECAST
PERCENT CORRECT SIGN
SUMMER (JUN - AUG/SEP)
1988 - 1990


AES MONTHLY TEMP. FORECAST
PERCENT CORRECT SIGN
AUTUMN (SEP - NOV/DEC)
1988-1990

(b)


PERS MONTHLY TEMP FORECAST
PERCENT CORRECT SIGN
WINTER (DEC - FEB/MAR)
1986 - 1990


PERS MONTHLY TEMP FORECAST
PERCENT CORRECT SIGN
SPRING (MAR - MAY/JUN)
1986 - 1990


PERS MONTHLY TEMP. FORECAST
PERCENT CORRECT SIGN
SUMMER (JUN - AUG/SEP)
1986 - 1990

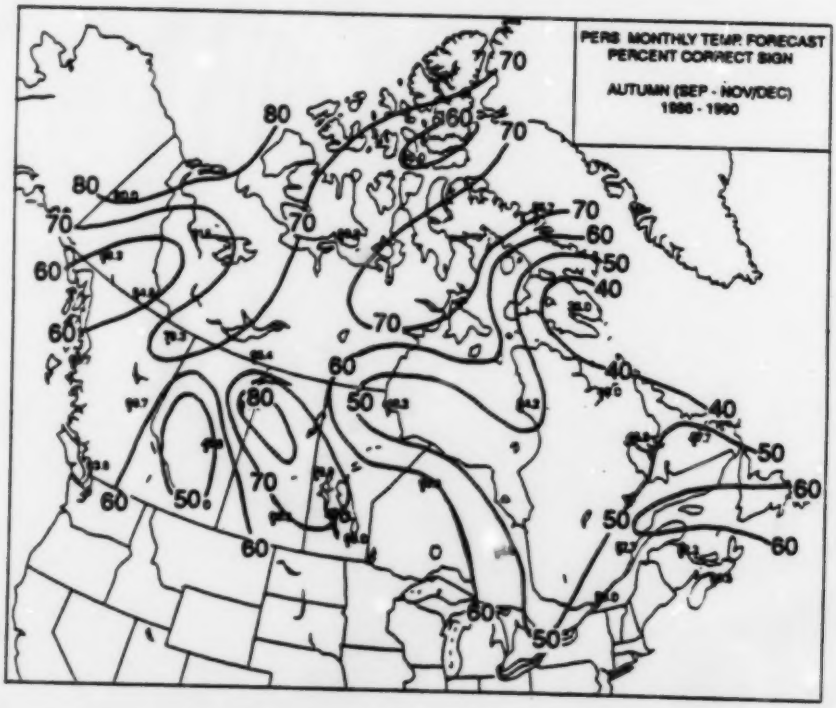
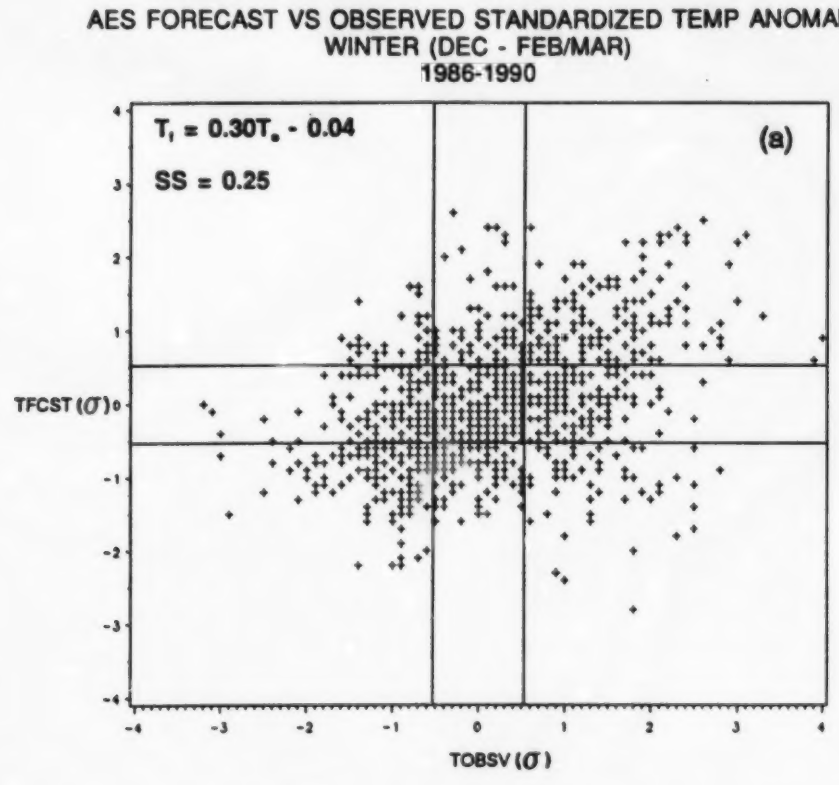
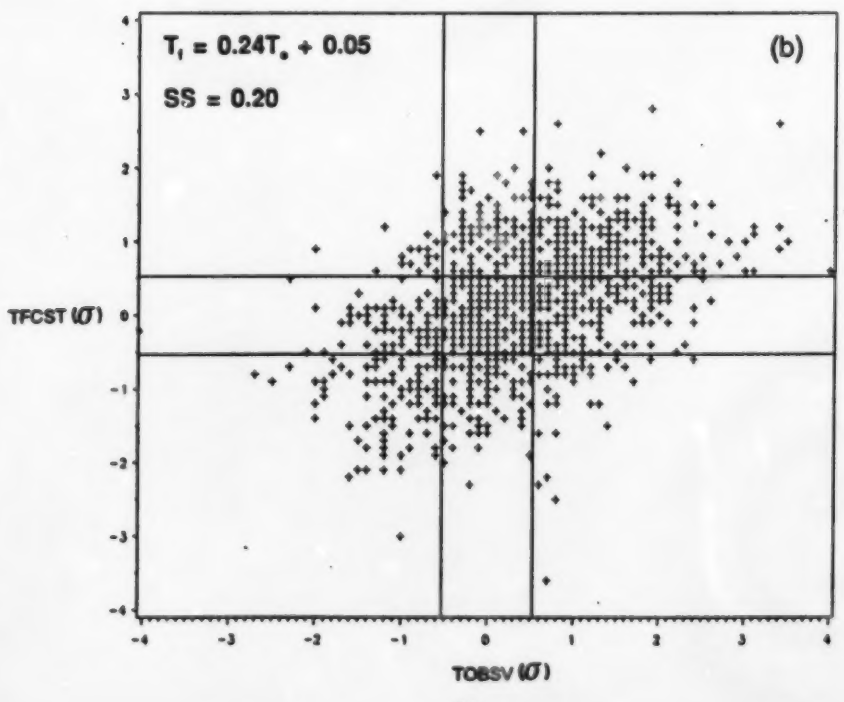
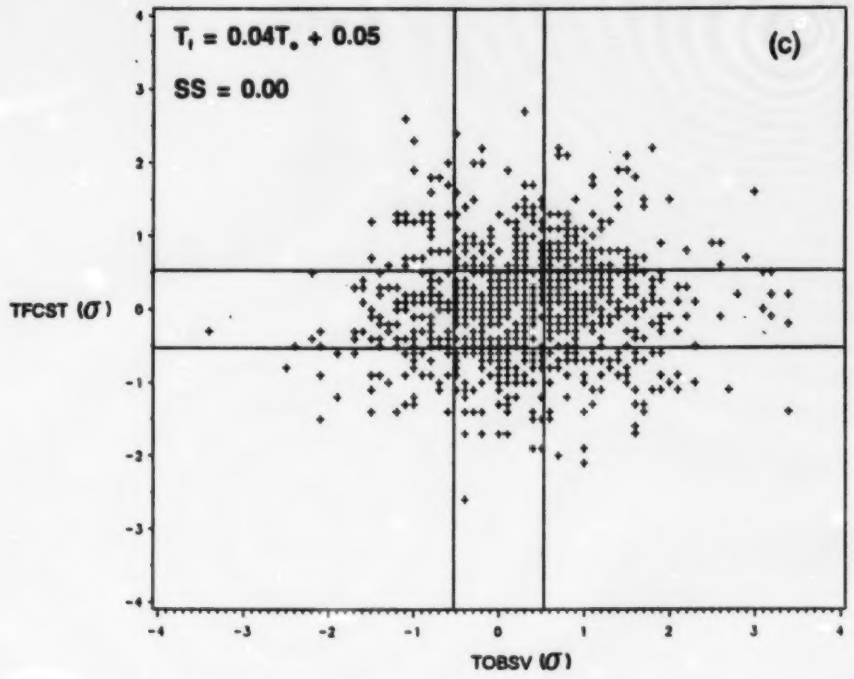

PERS MONTHLY TEMP. FORECAST
PERCENT CORRECT SIGN
AUTUMN (SEP - NOV/DEC)
1986 - 1990

Figure 5.10. Scatterplots of AES forecasts versus observed temperatures for (a) winter, (b) spring, (c) summer and (d) autumn.

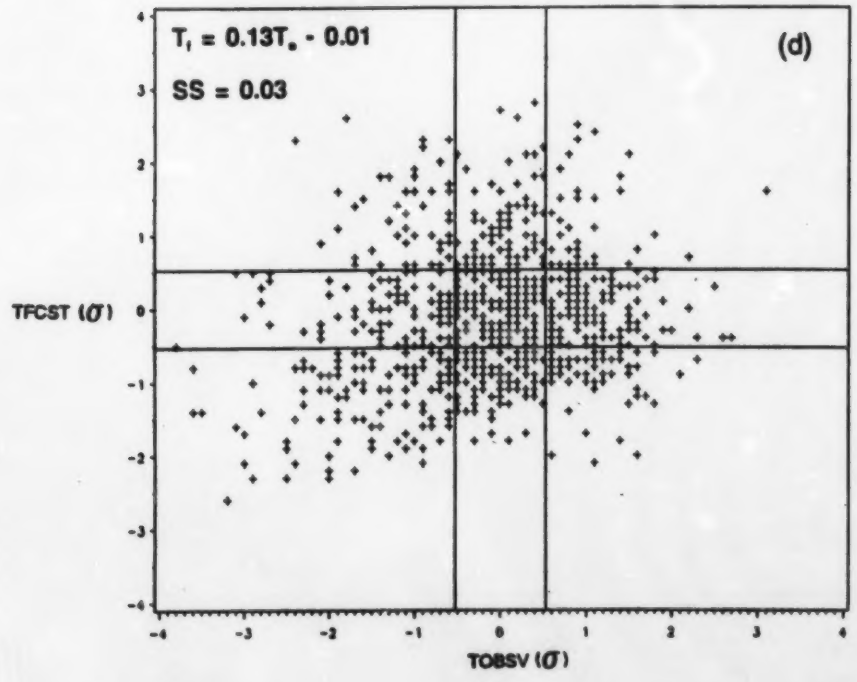




AES FORECAST VS OBSERVED STANDARDIZED TEMP ANOMALY
SUMMER (JUN - AUG/SEP)
1986-1990



AES FORECAST VS OBSERVED STANDARDIZED TEMP ANOMALY
AUTUMN (SEP - NOV/DEC)
1986-1989



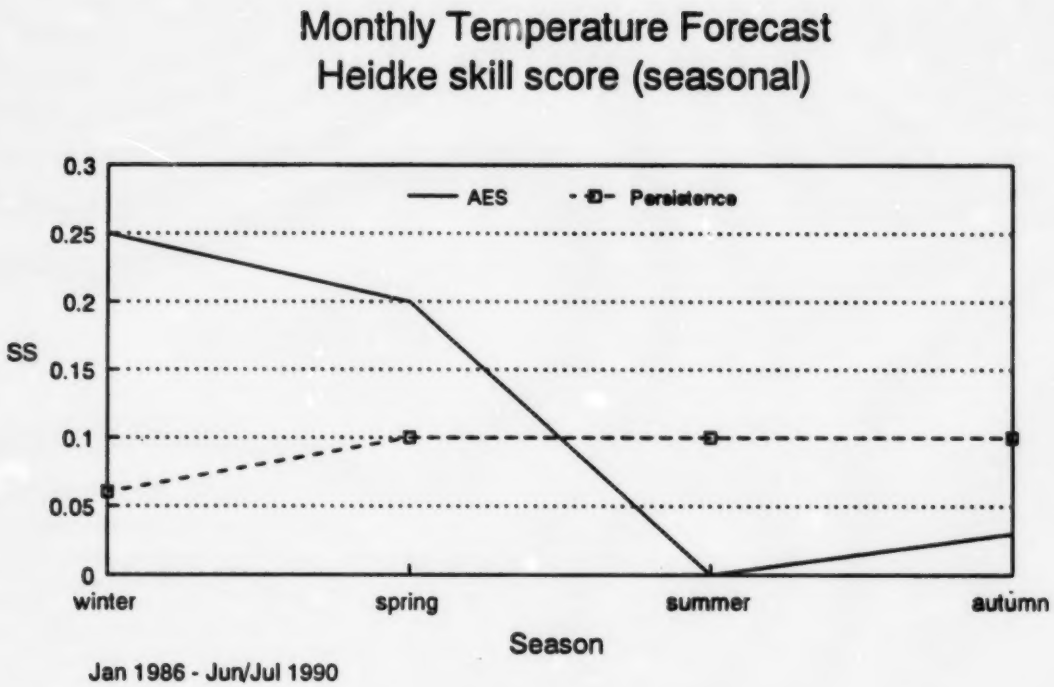
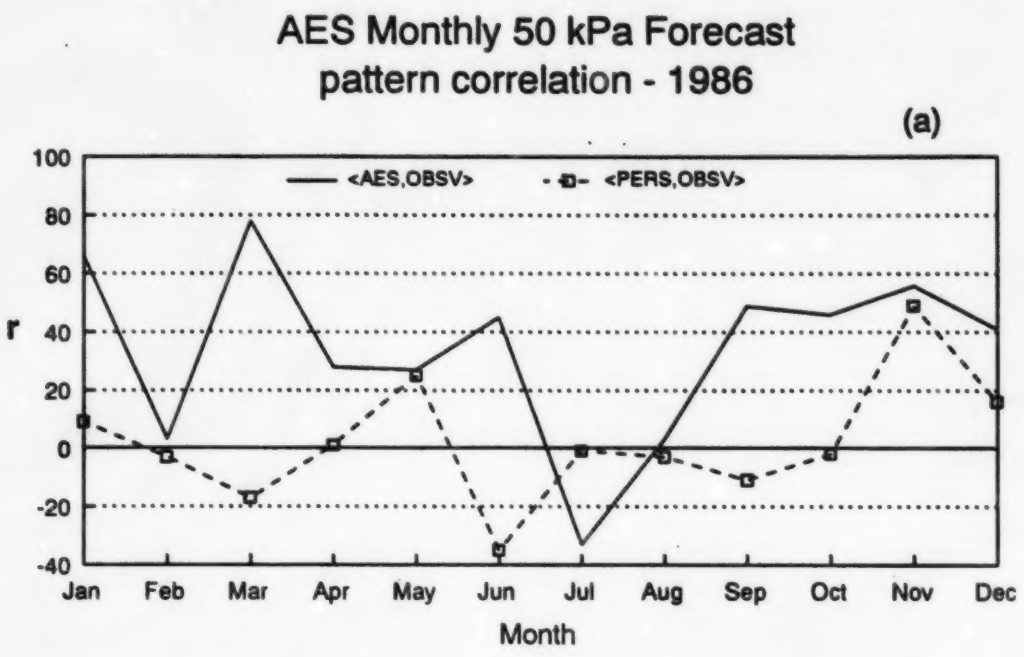
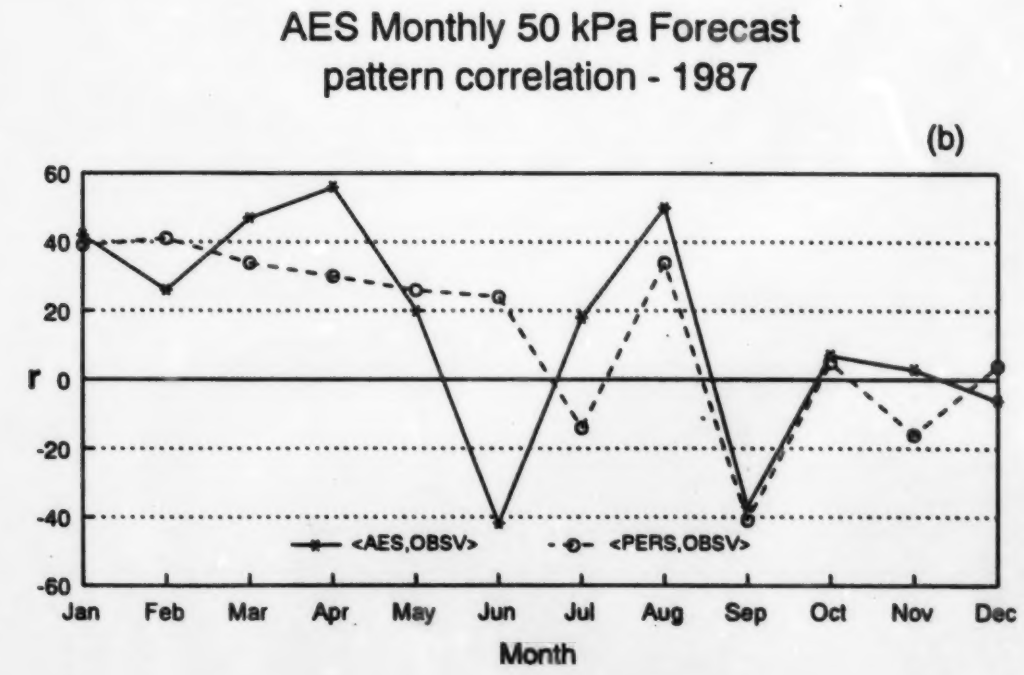


Figure 5.11. Heidke skill scores SS for the AES and the persistence forecasts for each of the four climatological seasons. Chance is used as a comparison.

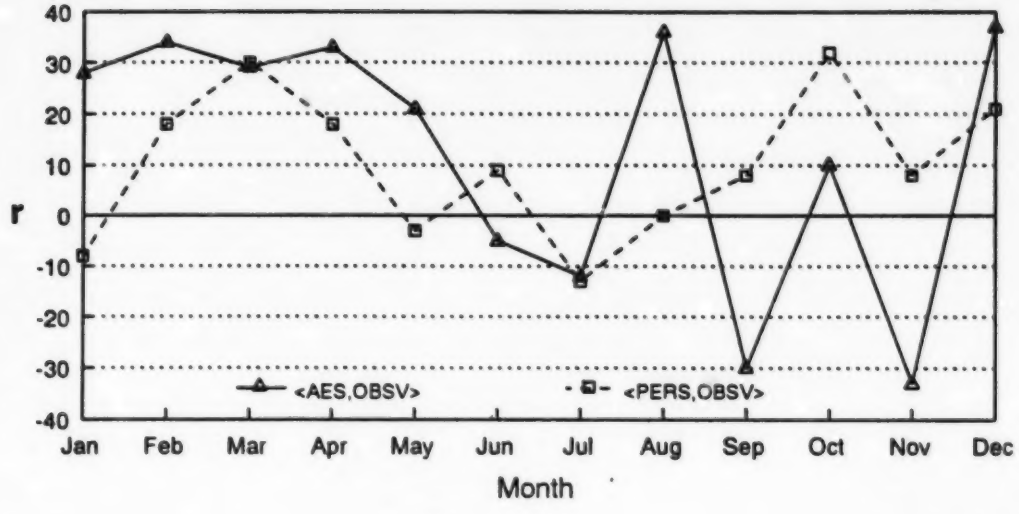
Figure 5.12. Pattern correlations between the pairs, AES and observed, and persistence and observed 50 kPa height anomalies, for (a) 1986, (b) 1987, (c) 1988, (d) 1989 and (e) 1990. The correlation is calculated for the network of 110 points shown in Figure 4.2.





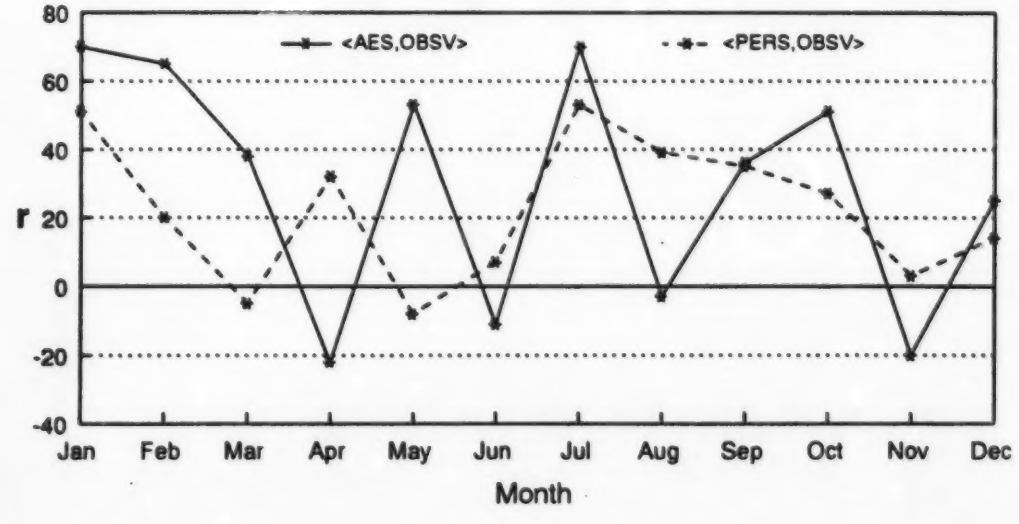
AES Monthly 50 kPa Forecast
pattern correlation - 1988

(c)



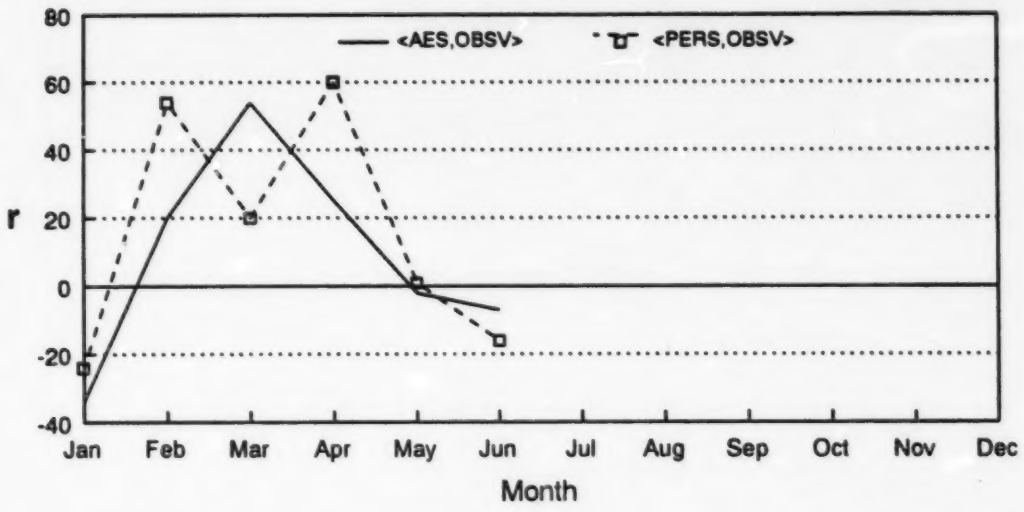
AES Monthly 50 kPa Forecast
pattern correlation - 1989

(d)



AES Monthly 50 kPa Forecast
pattern correlation - 1990

(e)



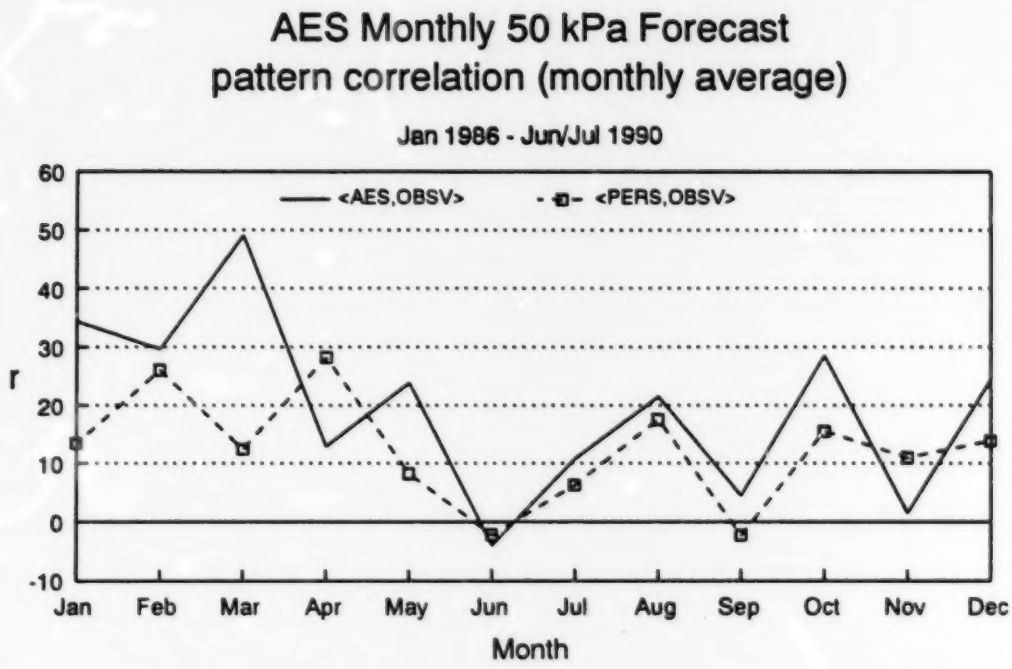


Figure 5.13. Mean monthly pattern correlations between the pairs, AES and observed, and persistence and observed 50 kPa height anomalies.

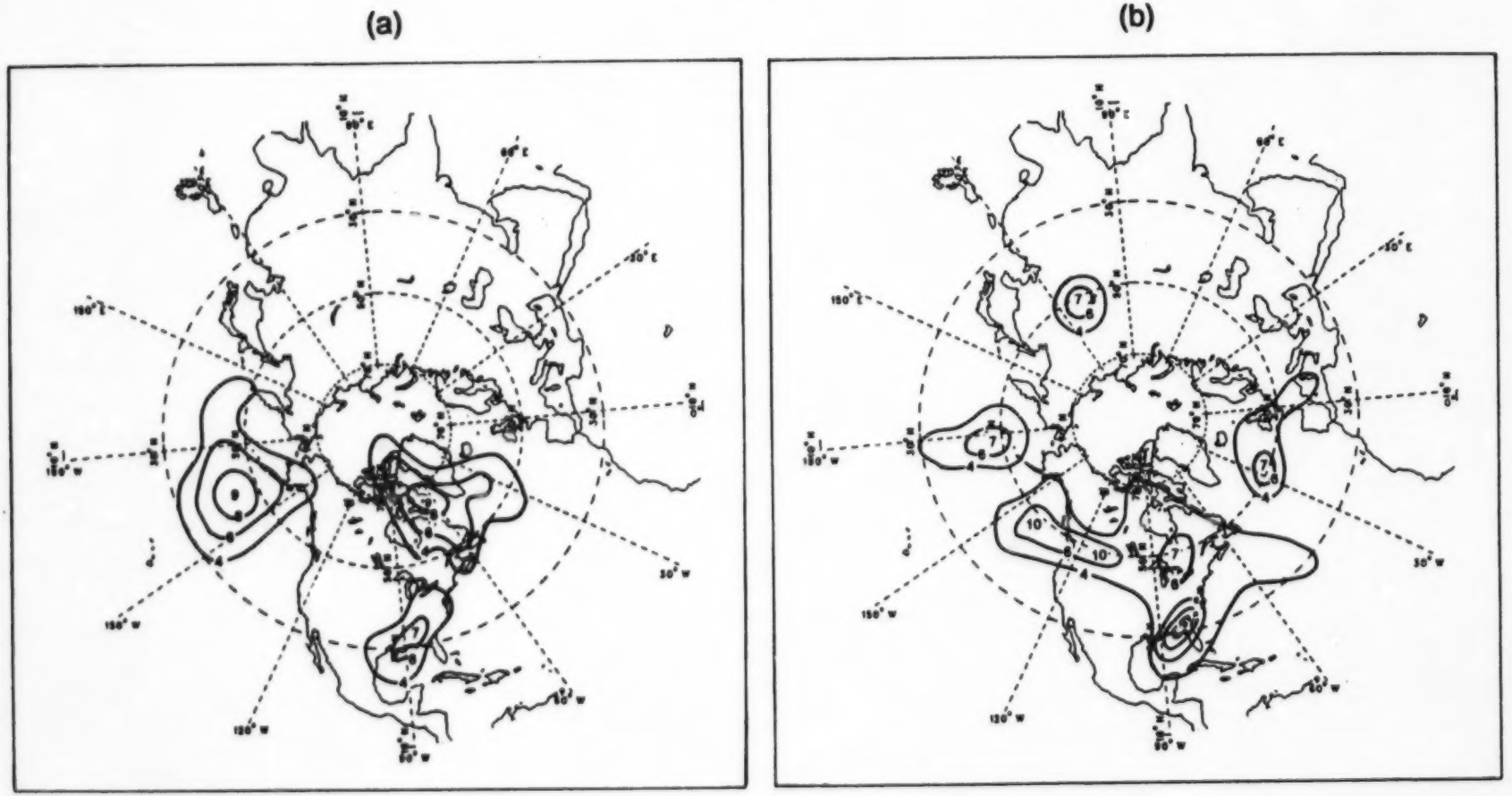


Figure 5.14. Variation in the per cent frequencies of the specified (a) negative and (b) positive height anomaly centres at 50 kPa.

Table 5.1 **Normalized contingency table for the AES and persistence forecasts for each of the four seasons.**

NORMALIZED CONTINGENCY TABLE
WINTER (DEC - FEB/MAR)
1986-1990
AES

	B	N	A	
F A	3.47	6.84	15.82	26.12
C N	11.12	22.96	12.96	47.04
S B	11.84	9.69	5.31	26.84
T				
	26.43	39.49	34.08	100.00
		OBSV		

HEIDKE SKILL SCORE SS = 0.25

NORMALIZED CONTINGENCY TABLE
WINTER (DEC - FEB/MAR)
1986-1990
PERSISTENCE

	B	N	A	
F A	5.20	14.69	14.49	34.39
C N	11.33	13.57	11.53	36.43
S B	9.90	11.22	8.06	29.18
T				
	26.43	39.49	34.08	100.00
		OBSV		

HEIDKE SKILL SCORE SS = 0.06

NORMALIZED CONTINGENCY TABLE
SPRING (MAR - MAY/JUN)
1986-1990
AES

	B	N	A	
F A	1.71	11.62	21.43	34.39
C N	7.90	18.57	17.71	44.19
S B	8.86	7.62	4.57	21.05
T				
	18.48	37.81	43.71	100.00
		OBSV		

HEIDKE SKILL SCORE SS = 0.20

NORMALIZED CONTINGENCY TABLE
SPRING (MAR - MAY/JUN)
1986-1990
PERSISTENCE

	B	N	A	
F A	4.29	13.90	22.00	40.19
C N	8.76	15.14	15.05	38.95
S B	5.43	8.76	6.67	20.86
T				
	18.48	37.81	43.71	100.00
		OBSV		

HEIDKE SKILL SCORE SS = 0.10

NORMALIZED CONTINGENCY TABLE
SUMMER (JUN - AUG/SEP)
1986-1990
AES

FCST	B	N	A	
A	3.52	10.11	9.89	23.52
N	10.66	21.98	21.76.	54.40
B	4.07	10.99	7.03	22.09
	18.24	43.08	34.88	100.00
		OBSV		

HEIDKE SKILL SCORE SS = 0.00

NORMALIZED CONTINGENCY TABLE
SUMMER (JUN - AUG/SEP)
1986-1989
PERSISTENCE

FCST	B	N	A	
A	5.27	15.38	19.56	40.22
N	7.80	17.91	13.85	39.56
B	5.16	9.78	5.27	20.22
	18.24	43.08	38.68	100.00
		OBSV		

HEIDKE SKILL SCORE SS = 0.10

NORMALIZED CONTINGENCY TABLE
AUTUMN (SEP - NOV/DEC)
1986-1989
AES

FCST	B	N	A	
A	6.19	10.12	5.12	21.43
N	11.67	18.93	15.48	46.07
B	13.10	12.38	7.02	32.50
	30.95	41.43	27.62	100.00
		OBSV		

HEIDKE SKILL SCORE SS = 0.03

NORMALIZED CONTINGENCY TABLE
AUTUMN (SEP - NOV/DEC)
1986-1989
PERSISTENCE

FCST	B	N	A	
A	5.60	16.07	20.36	42.02
N	8.21	17.62	13.81	39.64
B	5.12	9.05	4.17	18.33
	18.93	42.74	38.33	100.00
		OBSV		

HEIDKE SKILL SCORE SS = 0.10

6. Summary and recommendations

In the preparation of long-range temperature forecasts by the Atmospheric Environment Service, empirical orthogonal functions (EOFs) are used to filter out small-scale or spatially inconsistent circulation features of the primary 50 kPa forecasts. By a suitable mix of the multiple linear regression model based on the lagged correlation of the monthly 50 kPa height anomalies and the output from the global numerical weather prediction models (up to ten days), a set of main action centres (from 5 to 10) are identified by the forecaster. These centres are fitted to the first five EOFs and the resultant values from the reconstructed 50 kPa height field are used as predictors to specify surface temperatures over Canada.

Based on the analysis of a sample of 108 forecasts from January 1986 to June/July 1990, we conclude that the AES temperature forecasts have significant skill over persistence in both the two- and three-class forecasts, in winter and spring. However, the forecast skill is not significantly different from persistence in summer and autumn. We find that the skill of the two-class AES, NOAA and persistence forecasts are about the same, about 60%. In light of the demonstrated skill of the three-class temperature forecasts in winter and spring, it is justifiable to introduce three-class temperature forecasts particularly in winter and spring. The AES forecast at 50 kPa has shown demonstrable skill above chance in all months except June, and skill above persistence in nine out of 12 months.

Regionally, the AES forecasts show some rather high scores for winter and spring for western Canada and the East Coast. Persistence scores are particularly high for the Canadian Arctic in summer and autumn. The coupling between 50 kPa heights and the surface temperatures is weak in summer and autumn for the Arctic, possibly owing to the presence of extensive stratus clouds (Klein, 1985). In addition, 50 kPa height anomalies are also poorly forecast in these seasons (Figure 5.13). These two factors combine to produce low scores for surface temperature forecasts. A frequency analysis shows that points chosen at 50 kPa are nearly coincident with the areas of high variability in the historical data suggesting that the forecaster is trying to capture the greatest amount of spatial variance by means of the input points at 50 kPa.

Over the four and one-half year sample, consistent forecast skill over persistence has been shown for winter and spring. Can the skill be improved for summer and autumn? In light of significantly different circulation regimes in winter and summer (generally anomalies are smaller and weaker in summer), we should not expect the first five EOFs to capture the same percentage of the total variance. One possibility is to increase the number of EOFs used in fitting the specified points, from five to

perhaps seven or eight. Another way to increase the summer and autumn skill scores is to modify the current forecast procedure by making better use of persistence in the surface forecast.

We have demonstrated that monthly prediction skill varies with location and situation. One might wonder about other opportunities to improve the skill of the monthly forecasts. In recent years, heavy reliance has been placed on NWP to produce skilful longer range forecasts. Elimination of the systematic errors in large-scale model climatology during the next few years along with the introduction of new techniques to postcorrect NWP output or to assign a reliability value to the NWP output offer the best hope for deriving skilful forecasts from dynamical extended range integrations.

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